THE UNIVERSITY OF ALBERTA

ASPHALT STABILIZATION OF A PLASTIC FINE-GRAINED SOIL

by

DELMERE ROY BIRD

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF CIVIL ENGINEERING

EDMONTON ALBERTA

MAY 1963

ABSTRACT

In recent years highway researchers have sought new procedures for bituminous stabilization which would facilitate a better product at less cost. The investigation, on which this thesis was based, dealt with a low to medium plastic silty clay and an asphalt additive. The soil was a marginal material for soil bitumen as the liquid limit and plasticity index were slightly greater than those of the soils which are commonly used. Also, the amount by weight of material which passed the number two hundred sieve was in excess of the norm.

The unconfined compression test and a modified Hubbard-Field stability test were used to measure the strength of cylindrical specimens. Generally, the strengths were determined after a period of air curing and/or a period of soaking in water.

Based on the design criteria set forth by the author of that part of the Soil Stabilization Section dealing with bituminous soil and aggregate in the Highway Engineering Handbook (K. B. Woods, Editor-in-Chief), it was found that the standards of design were only partially satisfied.

ACKNOWLEDGEMENTS

The author wishes to extend his appreciation to:

Mr. K. O. Anderson, Associate Professor, Department of Civil Engineering, University of Alberta, for his formative criticism, continuous help, and loans of publications from his personal library;

The Royal Canadian Air Force under whose sponsorship the author was able to carry out his post-graduate program;

Group Captain E. R. Baker, the author's Air Force Headquarters' correspondent, for personal kindnesses bestowed;

The Highways Division of the Alberta Research Council for supply of soil and use of testing equipment;

The Husky Oil Refinery, Lloydminster, Saskatchewan, for the supply of asphalt.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

CHAPTER I

OBJECTIVE OF THE INVESTIGATION

<u>The objectives</u>. With respect to surface and base course highway construction, conceivably the time will come, and possibly is at hand, when stabilization of cohesive soils will be imperative. The current practice of using materials of the granular and cohesive granular classification will continue to predominate over cohesive fine-grained soils in stabilization methods only as long as economics justify. However, the necessity for fine-grained soil stabilization could be created by the depletion of the more suitable gravel and sand aggregates in a local area where haul distances and attendant costs prohibit their use, by the requirement to provide bases and surfaces for secondary and farm-to-market roads, and by an immediate need in civil defence and military emergencies where an area must be made trafficable. (1) *

The objective of this investigation was to study the suitability of a silty clay for bituminous stabilization characteristics in order that some of its potential for such a usage would be known. The soil chosen for this research was similar to those which occur over extensive areas of the Canadian western plains and thus represented a material which, by future necessity, could require improvement in its load-bearing capacity. Some of the strength characteristics of this low to intermediate

---

*Numbers in parentheses refer to the corresponding numbers in the List of References.

plastic soil have been investigated by Hvozdanski (2) who utilized a lime-pozzolan additive.

To aid in meeting the objective, the soil when mixed with a bitumen was examined for possible waterproofing and binding characteristics, for strength changes caused by an aeration or drying back period, and for strength changes which result from a curing period after compaction. The program was initiated with these aims in order to conclude, if possible, whether the types and grades of asphalt additive used could adequately stabilize the soil by varying the method of asphalt application to the moist soil and by altering the methods of mixing.

One of the latter methods was the foamed asphalt process which had as its objective the assessment of the merits of that process when a moderately plastic soil was used. Also, by altering the specimen preparation and testing procedures, an anticipated outcome was the comparison of results obtained by those procedures whereby a strength value in pounds per square inch might be correlated with an extrusion value in pounds. The extrusion value is a stability measurement which is developed by a "punching-shear type of failure." (3, Sec 18, p 65)

<u>Types of bituminous stabilization.</u> The types of bituminous stabilized mixtures which are used in highway construction may be divided into three principal groups. (3) Firstly, the sand bitumen type contains clean sands and a bitumen which provides binding properties. Secondly, the sand-gravel-bituminous mixture, where the aggregates possess frictional strength, has the bitumen additive to waterproof and provide cohesive strength to the mix. Thirdly, the soil-bitumen type is

composed of a cohesive fine-grained soil and bitumen which are blended to stabilize the moisture content of the soil. The moderately plastic silty clay material employed in this investigation, with bitumen as an additive, thus can be typed as soil bitumen.

Test equipment and terminology. To facilitate these objectives, the equipment used in the investigation was the University of Alberta compaction apparatus, the Hubbard-Field compaction and extrusion apparatus, and unconfined compression testing machines. The University of Alberta compaction apparatus allows the preparation of two-inch diameter specimens, as does the Hubbard-Field compaction apparatus, which reduces the amount of material required for an investigation. Where possible, the test equipment was employed in the manner prescribed by the American Society for Testing and Materials (ASTM), and thus ASTM criteria of design have been acknowledged when results have been evaluated.

Most terminology used in this thesis is that common to the science of soil mechanics. One uncommon term is "total volatiles." This term refers to the percentage sum of water and hydrocarbon volatiles in a mixture based on the dry weight of the soil. The term "aeration" means the exposure of the loose mixture to air drying. This drying may be hastened by an intermittent or continuous mechanical action imposed on the mix. "Curing" means the treatment of the soil bitumen after compaction during which water and/or hydrocarbon volatiles evaporate. The expression "extrusion value" alludes to the maximum resistance that is developed by a test specimen when it is forced

through an orifice at a constant rate. The resistance is measured in pounds.

Organization of the investigation. Following this chapter will be one dealing with essential soil and asphalt properties, design criteria, allied investigations, and literature review. Chapter III will discuss some of the mechanics of soil-bituminous stabilization, followed by an outline of the testing program in Chapter IV.

The results of the investigation and discussion of the results will be presented in Chapter V where the majority of figures will show per cent total volatiles plotted against those properties which are a measure of the value of the stabilized mixture. These properties will be dry density, unconfined compressive strength, per cent expansion, per cent absorption, per cent air voids, and extrusion value. The terminal chapter will contain the conclusions and recommendations.

Hence in this investigation the overall objective is to examine the asphalt stabilized properties of a silty clay soil and to compare the results with information contained in the literature.

CHAPTER II

GENERAL ASPECTS OF THE INVESTIGATION

Loess, a uniform fine-grained soil was one of the materials combined with asphalt from three to five thousand years ago in the Middle East. (4) Deposits of asphalt from Asia Minor were used as the key material in many major construction works. Thus these civilizations were well aware of asphalt's adhesive and waterproofing qualities. (5)

The use of foamed asphalt for stabilizing soil in the surfacing of secondary roads has been studied by Csanyi (6), and Nady and Csanyi. (7) Special equipment and good control are required, but according to these investigators, asphalt in the foamed state can coat fine-grained soil particles which are cold and damp. Water assists in the uniform distribution of the foamed binder throughout the mix.

From olden times to the present, the advancements made with respect to highway building have evolved from scientific studies. Most of the large projects involving soils and asphalt are now designed by laboratory investigations prior to construction. The results of an investigation assist in the preparation of project specifications which include the required phases of construction and basic property requirements of the soil and asphalt such as moisture content, temperature, and gradation.

I. BASIC SOIL AND ASPHALT PROPERTIES

Gradation. The gradation requirements for a soil known to have given satisfactory service, when stabilized with bitumen (8) (3), are as follows:

Screen Size	Per cent Passing
# 4	50 - 100
# 40	35 - 100
#200	10 - 50

Atterberg limits. The liquid limit of a potential soil for soil bitumen should be less than thirty and the plasticity index should be less than twelve. Woods (3) allows an increase of these percentages to forty and eighteen, respectively, provided the soil can be pulverized.

From the above gradation and Atterberg limits, those soils which can be classified as granular materials A-1-b, A-2-4, A-2-6 and silt-clay materials A-4 and A-6 (Highway Research Board (HRB) soil types) can be used for asphalt stabilization. (9) The silt-clay materials fall into the soil bitumen stabilization group previously defined in Chapter I. It is possible that the granular groups listed could also do so.

Nady and Csanyi (7) in their paper presenting the use of foamed asphalt in soil stabilization, state that the foaming process can coat soils from A-2-4(0) to A-6(9). Hence the previously unsuitable A-5 group, having a minimum liquid limit of forty-one and a maximum plasticity index of ten, is introduced. However, the minimum thirty-six

per cent passing the number two hundred screen and maximum group index of twelve is also imposed.

Tar and asphalt, types and grades. For soil bitumen stabilization, manufactured asphalt types listed (3) for use are four liquid asphalts. These are emulsions, slow curing asphalt (SC), and the two cutback asphalts known as medium curing (MC) and rapid curing (RC). Grades one to four inclusive of the SC, MC, and RC types are applicable. Also listed are road tars (RT), grades one to four. The foamed asphalt process utilizes a penetration grade of asphalt cement in conjunction with saturated steam.

II. DESIGN CRITERIA

For stabilization purposes, soils have been subdivided into three groups: granular, cohesive granular, and cohesive for percentages of silt plus clay of 0-20, 20-35, and 35-100, respectively. (1)

The criteria to be met by soil bitumen specimens when moulded and tested by the ASTM designation D915-47T, "Testing Soil-Bituminous Mixtures," are that the minimum extrusion value before and after the absorption test should be one thousand pounds and four hundred pounds, respectively, the expansion during absorption should not exceed five per cent, and the water absorbed during the absorption test should not be greater than seven per cent. (3)

Woods (3, Sec 21, p 94) also refers to Winterkorn's (10) newer method of soil bitumen design which makes use of the unconfined

compression test. Specimens of various bitumen contents are compacted to the same density as the maximum dry density of the soil only. After moulding, these specimens are left to dry in the air until they reach constant weight. One-half of the specimens are tested by an unconfined compression test. The other half of the specimens are put to soak in total immersion for seven days and then tested in the unconfined compression manner. The criteria, as established for this testing method, influence the selection of the bitumen content which has the smallest dry to wet strength ratio, provided the wet strength is greater than seventy-five pounds per square inch. This wet strength criterion compensates for, or includes the expansion and absorption limitations of the first set of criteria, as the total immersion is a more severe test than the ASTM partial immersion. The wet strength criterion applies to base construction. (9)

III. ALLIED INVESTIGATIONS

The word "allied" is used in the heading of this section to denote the closest agreement of material types used in other investigations to that of the material in this one. Examples of similar investigations in the literature are relatively few. Possibly this is because the soil bitumen type of construction is in its development stage and is usually thought to be of intermediate quality. To some extent, experimental work in soil bitumen has involved field projects which included "trial and error" methods using various asphalts and soils. The results of the best mixes for a geographic area have not been widely published

and consequently little information on construction controls is available.

The Edmonton locale soil used in this investigation, being a silty clay, has an HRB classification of A-6(9). The Atterberg limits of the soil, which help to decide this classification, are a liquid limit of 32.7 per cent and a plastic limit of 19.3 per cent. The plasticity index is 13.4 per cent. This A-6(9) classification is at the fine-grained end of the scale specified by Nady and Csanyi. (7) Thus, from the aspect of soil bitumen suitability, the soil is a "border line" material.

These investigators reported the stabilization of approximately one-half a mile of road by the foamed asphalt process in 1957. Of the fourteen soil classification determinations, seven were A-4 soils and seven were A-6. One of the latter seven had a group index of nine, and the average liquid limit and plastic limit of these A-6 soils were thirty-three and nineteen, respectively, giving a plasticity index of fourteen. These values are almost identical to the soil investigated herein.

On the project reported by Nady and Csanyi (7) the field moisture average content, determined immediately before foamed asphalt application, was 11 per cent. This was three percentage points lower than the optimum for the soil alone, by the Standard Proctor compaction test. The asphalt was applied by four spearate passes of a pulvi-mixer having twelve asphalt nozzles and the investigators reported that many of the specimens made from samples secured after the final asphalt pass withstood three freeze-thaw cycles with no distress. This meant that the samples were waterproofed to some extent but did not

eliminate the possibility of distress if the number of freeze-thaw cycles were increased. Another of their conclusions was that, for the soils treated, visual inspections indicated best results were obtained when 6 per cent of an asphalt cement was used.

In a paper by Katti, Davidson, and Sheeler (10), the investigators list an A-6(9), silty clay soil, but do not give any specific results. One of the conclusions, however, was that seemingly homogeneous soil-cutback asphalt systems can be produced with silty and clayey soils if the amount of mixing water is at least equivalent to the liquid limit of the soil being mixed. This water content, 33 per cent or greater, was not explored in this thesis.

Studies have been made by Hoiberg and Brown (11) which pertain to slow curing liquid asphalts and fine-grained soils. They have theorized on the mechanics of stabilization and their theory will be included later in this dissertation.

IV. LITERATURE REVIEW

The literature which was most closely allied with cohesive soil stabilization has been briefly mentioned in the preceding section. The extensive literature on granular and cohesive granular stabilization, by means of asphalt, is in agreement on many aspects of the theory and construction practices. One of the aspects which appears to be somewhat controversial is that of the amount of aeration to which a mixture should be subjected prior to compaction. Most investigators agree that asphalt has certain limitations in its stabilizing effectiveness and that a

need for research exists. This latter need is in the field of marginal materials, such as those HRB soil types not listed for asphalt stabilization use by Winterkorn. (9)

There is a general agreement that the science of soil stabilization must include economics, where first costs and maintenance costs are considered, and that moisture content is the prime factor which influences soil engineering properties of which the most important is load-bearing capacity. An important objective of soil stabilization is to eliminate detrimental moisture content changes.

<u>Soil bitumen.</u> A soil bitumen mixture is one designed "to stabilize the moisture content of cohesive, fine-grain soils." (3, Sec 21, p 86) Bituminous materials help to plug or block the soil capillaries and form a partial protective film around the soil aggregation. The greater the amount of capillary blocking and protective films, the greater the prevention of "appreciable amount of moisture change within the soil mass" and the maintenance of "the inherent cohesive strength of the soils." (3, Sec 21, p 86) If these two functions are performed by a bitumen additive the soil has been "waterproofed." A cohesive soil by itself usually has satisfactory bearing capacity for highway use at low moisture content, but stability is rapidly lost as the moisture is increased. Bituminous materials are used with cohesive soils as waterproofing agents to maintain the low moisture content and thus act as a stabilizing material.

The ideal condition, from the standpoint of waterproofing, is to coat the individual soil particles with a coherent film of a stable, water-insoluble resinous substance which will prevent water from reaching the particle surfaces or will prevent capillary water migration into the consolidated porous soil mass. At the same time, this waterproofing condition, brought about by the resinous material causing individual soil particles to adhere to one another (12), must not be counteracted by a state of excessive lubrication. Only if these ideal conditions are met can any worthwhile contribution be given to the tensile and the shear strengths of the compacted soil mass.

Limitation of asphalt. The use of petroleum-derived asphalt and tar, substances which are used for particle coating of fine-grained soils, has been receiving increased attention. The limitation of their stabilizing effectiveness is believed to be:

(a) the difficulty of achieving uniform asphalt distribution in a fine-grained soil,

(b) the usual inability of asphalt to coat and adhere to wet soil particles,

(c) its sensitivity to destruction by water of any bond which it might have with the soil, and

(d) the detrimental influence on strength as its amount in a soil mixture is increased.

The optimum amount of asphalt distribution varies for fine-grained soil with changes in the type and grade of asphalt used. The

degree of distribution affects expansion--absorption properties as well as strength characteristics. "An intimate mix does not produce the most desirable stability properties of the compacted mixture." (10) In soil stabilization work it is desirous to overcome the relatively high viscosity and water-immiscible properties of asphalt, and the hydrophilic properties of soil grains.

With a fine-grained soil these problems can be paramount but the practice is to attempt to eliminate them by increasing the fluidity of the asphalt, by determining the favorable water content, and by utilizing a mixing procedure which gives best results. Generally, however, asphalt and related materials have been found to be of limited utility as stabilizers for fine-grained soils.

The function of water. The amount of bitumen required for stabilization depends essentially on the affinity of the bitumen to the soil material. The quantity of water present affects this affinity. As bitumen predominantly acts as an electronegatively charged colloid (a gelatinous substance, insoluble, which remains suspended in a fluid medium), "the amount of bitumen required increases with the number of electronegative charges located on the surface of the material to be stabilized." (13) Other factors such as void ratio, soil plasticity, and sources of bitumen also influence the quantity required.

One investigator (1) has written that the plastic state may be considered to begin as soon as the active surfaces in the soil system are covered with films of water that are sufficiently thick to be continuous and to have lubricating properties. It has also been written (11) that

the mixing of clayey soil-water-asphalt systems is nearly impossible, within reasonable mechanical limitations, when the moisture content lies within the plastic range of the soil-water system.

There appears to be unanimous agreement between investigators that the role of water in bituminous stabilization is a very important one; important because of its lubrication qualities which aid uniform distribution of asphalt and compaction. Katti, Davidson, and Sheeler (10) have made use of a "Compromise Moisture Content" (CMC) whereby desirable maxima and minima values, determined by testing of the bituminous mixtures, were used as a datum for the calculation of per cent deviation from the maxima and minima values for each moisture content used in the moulding of specimens. The properties of the mixtures used for these calculations were moisture content after seven days of specimen soaking, bearing value, and dry density. A graph was made of the sums of the per cent deviation from the three datums for each moulding moisture content. The CMC was then chosen where the minimum of the curve occurred. It was found that the CMC was very nearly equal to that moisture content which produced optimum Standard Proctor density for the soil alone and that the CMC represented "a mixing moisture content at which a compromise degree of asphalt distribution" (10) occurred.

The foamed asphalt principle, previously mentioned as a process which made use of an AC and saturated steam, appears to have a different water requirement for the production of the most stable mixture than do processes using cutback asphalts. In the foamed process the saturated

steam disperses the AC in globules to produce two basic types of foam; one type is in the form of individual small bubbles, the other type in the form of a foam mass where the bubbles are joined together. (6) The mechanics of the foamed principle is further discussed in Section II of Chapter III, as well as later in this chapter,

The original investigators (7) of the foamed asphalt process report that the moisture content requirement for satisfactory bitumen distribution in the soil, by that process, is low, and that it should be between optimum and that necessary to assist in breaking up agglomerates of soil particles. On the specific project reported, enough water was added, where necessary, to accomplish this pulverization which permitted the foamed asphalt to penetrate the lumps. In a paper by Curtis (14) it was reported that the correct moisture content was as equally important as the asphalt content. This was in reference to a sand of which 69 per cent passed the number 80 sieve and 32 per cent passed the number 200 sieve.

In soil-bituminous stabilization where water may be added to bring about asphalt distribution and where the soil is "worked" both prior to and during the stabilizing operation, the water and disturbance can change particle arrangement and interparticle forces. (15)

<u>Physico-chemical phenomena.</u> Physical and chemical properties are important in the proper stabilization of soils, especially those which do not possess a granular skeleton. (1) If a drop of asphalt and a drop of water are placed on a mineral surface, side by side, the two

contend for possession of the surface. (16) The molecular attraction of fluid for mineral, influences the spreading action of the particular fluid. At the same time the spreading is restrained by the surface tension which tends to keep it in spherical form. The resultant of these forces decides whether asphalt or water occupies the surface of the mineral. Thus a desired condition is to use an asphalt which has "displacement of water" characteristics.

Andrews and Noble (17) have published a table showing average contact angles between an MC-2 and four soils; two heavy clays and two loessial soils. They show that the contact angle is decreased when the moisture content is increased (up to a value of 15 per cent) and conclude that the asphalt is not completely non-wetting, but spreads on soil with difficulty.

Winterkorn (1) stated that the water-affinity of soils was a function of their ratios of silica to the sesquioxides of aluminum and iron, and a function of their adsorbed cations. This degree of affinity and the polar molecules present in the mixing bitumen influence the bond formation of water and asphalt to the soil. Here emphasis has been given to polar phenomena.

In foamed asphalt manufacture, the surface tension and viscosity of the asphalt are significant both in the mixing and placement of the product. (6) The interface tension developed between the film of binder and an aggregate particle depends largely upon the surface tensions of the two materials. The foaming principle is the generation of binder surface tensions, in relation to that of the aggregate, such that the

surface moisture on the aggregate can be displaced and a strong physical bond created between the binder and the aggregate.

Csanyi (6) also reports that "the physical properties of a bituminous binder can be temporarily modified without altering the chemical consitution of the binder by foaming the binder." This modification is the lowering of the viscosity, "to provide easier and more uniform distribution of the binder during mixing," which is "restored to normal during compaction of the mixture, permitting it to set rapidly."

In this literature review the questions of density, stability, and compaction have not been discussed. Their coverage is included in the succeeding chapter. The authorities (3) (10) (19) (18), in general, agree that the best density for the stabilized soil bitumen is approximately equal to the Standard Proctor dry density of the natural soil alone and that therefore changes in density with additions of asphalt admixtures should not be used as a criterion for stability. Also, it is most important to provide proper compaction to high densities at closely controlled moisture contents during construction.

CHAPTER III

MECHANICS OF SOIL BITUMINOUS STABILIZATION

I. LIQUID ASPHALT STABILIZATION

Cutback asphalt stabilization is usually carried out by:

(a) bringing the soil to its optimum water content and mixing with the asphalt,

(b) compacting the mixture, and

(c) curing the mixture.

During a period of aeration prior to compaction and a period of curing after compaction, the water and cutback solvent is allowed to evaporate. Mechanical aeration hastens the evaporation process. If it is desired to dry a mixture, the mechanical aeration method is usually employed.

The timing of compaction and the amount of curing appear to be influenced by the desired immediate use of the product or the desired end result. Some authorities (3) (18) stress the need for drying out before compaction to provide high initial stability, at the same time emphasizing that too dry a mixture is not desirable. Others (10) advocate compaction immediately after mixing.

The optimum moisture content for mixing is that percentage, which when uniformly distributed throughout a fine-grained soil, facilitates a uniform asphalt distribution, compaction, and strength. This moisture control is necessary in a fine-grained soil to reduce soil agglomeration, which can occur on both the dry and wet side of

optimum, during the mixing process. Upon the addition of cutback asphalt, a subdivision of the asphalt probably takes place (particularly when pressure sprayed) whereby the asphalt coats agglomerates of soil particles which are surrounded by water films. A waterproofing process, which aids in the stability of the dry and compacted soil, takes place. With increasing amounts of fine material in the soil, the amount of water required for thorough distribution of the asphalt becomes greater. (10)

If the concentration of water molecules around the surfaces of soil grains is not too great, a strong linkage between particles is obtained. On removal of water, as in the curing process, the links become shorter and stronger so that the cohesion (hardness of the crumb) of the clay is increased. When moderate amounts of asphalt are mixed with a fine-grained soil, the cohesion or hardness of the crumbs is reduced somewhat but the ability of the compacted mix to absorb water is usually also reduced. (11) This aids the maintenance of strong linkages between particles which improve the bearing value of the soil mix.

When the soil mass is compacted the structure consists of partial or completely asphalt coated agglomerates, individual soil grains, water, asphalt, and voids. The water and asphalt droplets probably help to fill the voids other than those within the agglomerates. The agglomerate (or small aggregate) formation is the tendency when mixing asphalt with a fine-grained soil.

When evaporation of water takes place, there exists the increased possibility of a fluid asphalt adherence to a larger portion of the soil

particle surfaces. This could be a natural internal migration, the rate and extent of which varies with the loss of hydrocarbon volatiles, or with mechanically induced action imposed at the proper time. Thus, within the fluid phase, the evaporation rates of water and hydrocarbon volatiles could influence the properties of the compacted product as to cohesive strength, durability, tendency to swell, and tendency to absorb moisture. During the process of mixing (up to seven minutes), the hydrocarbon volatile loss in the presence of water is negligible. (10) Investigations made by one researcher (19) using one specific medium curing cutback asphalt and a silty sand, showed that the variation with drying time in the rate of evaporation of hydrocarbon volatiles and water from both compacted specimens and loose mixtures, was similar; rapid at first, then levelling off. Also, water evaporated at a much faster rate than the hydrocarbon volatiles. This was neither influenced by the amount of initial mixing water or by the amount of cutback.

II. ASPHALT CEMENT STABILIZATION

A recent stabilization method has been that of foaming an asphalt cement where the only volatiles in the mix is the soil moisture and a very small amount of water vapour which is introduced if wet saturated steam is used to disperse the asphalt. The process is brought about by injecting saturated steam into heated asphalt at the throat of a nozzle (Figure I). Foamed asphalt cement is in the form of bubbles (6), whose thin films have natural surface tension forces available to coat soil particles on contact. The surface tension spreads the thin

CROSS SECTION OF FOAMED ASPHALT NOZZLE

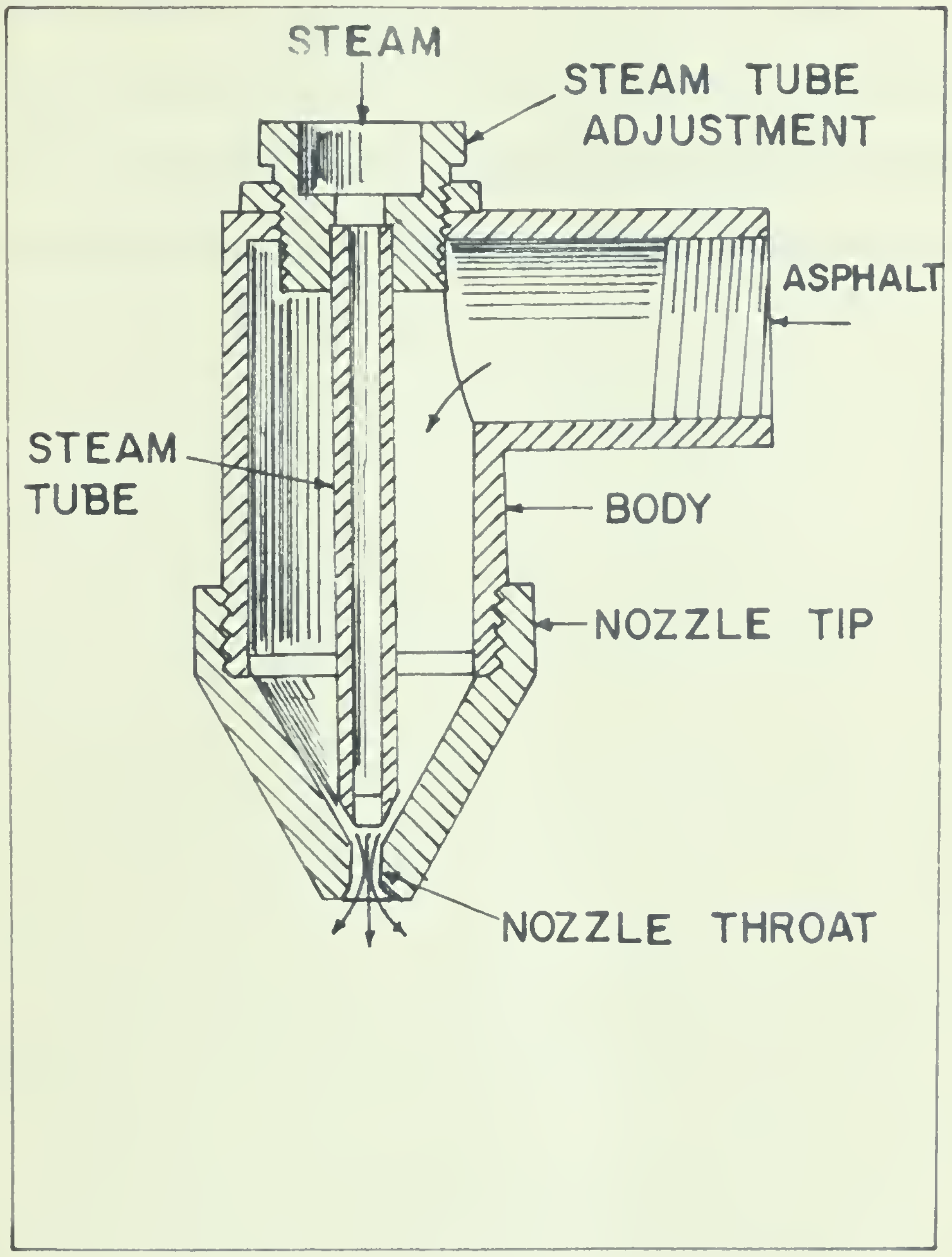


FIGURE 1

films of binder, as they break, forcefully and rapidly over the surface of the aggregate. With proper control of the asphalt and steam pressures, and the correct positioning of the steam orifice in relation to the mixing nozzle, the thin films with the foam as the vehicle (14), are produced. One claim made is that the foamed asphalt penetrates small voids and crevices during the mixing cycle. Also, it is reported that some physical properties of soils, such as stability and freeze-thaw resistance, are improved by stabilization with foamed asphalt, and that the compaction operation may immediately follow mixing.

CHAPTER IV

TESTING PROGRAM

The testing program involved the moulding of cylindrical soil specimens which contained varying amounts of water and asphalt. The moulding was carried out by both dynamic compaction and static compaction.

The hand-mixing method, employing an MC-2, was used in the preparation of mixtures from which dynamically compacted specimens were moulded. The statically compacted specimens were moulded from mechanically-mixed trial batches of moist soil and MC-O, and moist soil having an 150-200 penetration AC as the additive.

Moulded specimens were subjected to an unconfined compressive strength test and to a modified Hubbard-Field stability test, both before and after a seven-day soaking period. The aim of this mixing, moulding, and testing was to find soil bitumen mixtures which would satisfy expansion, absorption, and stability criteria.

The procedure for specimen preparation, both dynamically and statically compacted, is contained in Appendix A.

I. MATERIALS

The soil and asphalt. The fine-grained soil used in this investigation was obtained from an area adjacent to Alberta Provincial Highway 16 immediately west of Edmonton. Ten per cent of the original soil was retained on the number four sieve and twenty per cent was retained on

the number twenty sieve. It was pulverized in order that one hundred per cent would pass the number ten sieve.

The soil has previously been designated an A-6(9), a silty clay. It can also be designated as a silty loam by the U. S. Bureau of Soils chart, a CL by the Unified system, and an E5 by the Federal Aviation Agency method. The properties of the soil are shown in Table I.

All asphalts (MC-0, MC-2, 150-200AC) used in the testing were obtained from the Husky Oil Refinery at Lloydminster, Saskatchewan. The analysis for the MC-0 and 150-200 penetration AC are contained in Tables II and III. No analysis data was available for the MC-2, so, in the calculations, the minimum asphalt residual for that grade of cutback was assumed.

II. SPECIMEN PREPARATION AND APPARATUS

Dynamically compacted specimens. All specimens moulded in this investigation were cylindrical in shape and had a height of 2 ± 0.05" when compacted in a two-inch diameter mould. The initial testing program employed the University of Alberta dynamic compaction apparatus (Plate 1A). Samples made of soil, water, and MC-2 asphalt were prepared using two compactive efforts. These efforts were identical to the Standard Proctor and Modified Proctor compactive efforts, 12,400 and 56,300 foot-pounds per cubic foot, respectively. Thus the compactive efforts employed served as an experimental base only, but their selection does facilitate the comparison of densities as obtained by the two-inch mould and the standard four-inch diameter

TABLE I

SOIL PROPERTIES

Specific gravity	2.74
Liquid limit (%)	32.7
Plasticity index	13.4
HRB designation	A-6(9)
Standard Proctor:	
Dry density (lbs./cu. ft.)	111.2
Optimum moisture (%)	15.3
Modified Proctor:	
Dry density (lbs./cu. ft.)	121.5
Optimum moisture (%)	12.3
Uniformity coefficient	65
Soil grain size (MIT grain size scale):	
Per cent sand sizes	42
Per cent silt sizes	45
Per cent clay sizes	13

TABLE II

MC-O ANALYSIS

Specific Gravity @ 60° F. -- 0.9321

A.P.I. Gravity @ 60° F. -- 20.3

Flash T.O.C. -- 100° F. Water -- Nil %

Saybolt Furol Viscosity @ 77° F. -- 116 seconds

Distillation: % of Total Distillate over

437° F.	1.1
500° F.	40.2
600° F.	82.7
680° F.	100

% Residue to 680° F. volume by difference - 56.5

Residue: Penetration @ 77° F. (100 grams, 5 seconds) 277

Soluble in Carbon Tetrachloride 99.8%

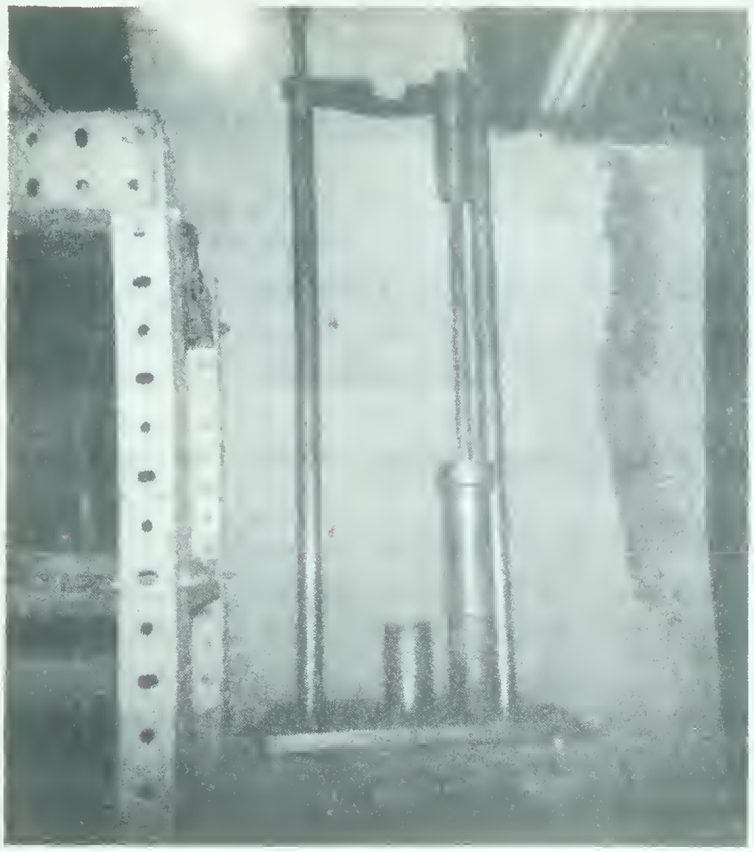
Ductility @ 60° F. (5 cm. per minute) 100 + cm.

TABLE III

ASPHALT CEMENT ANALYSIS

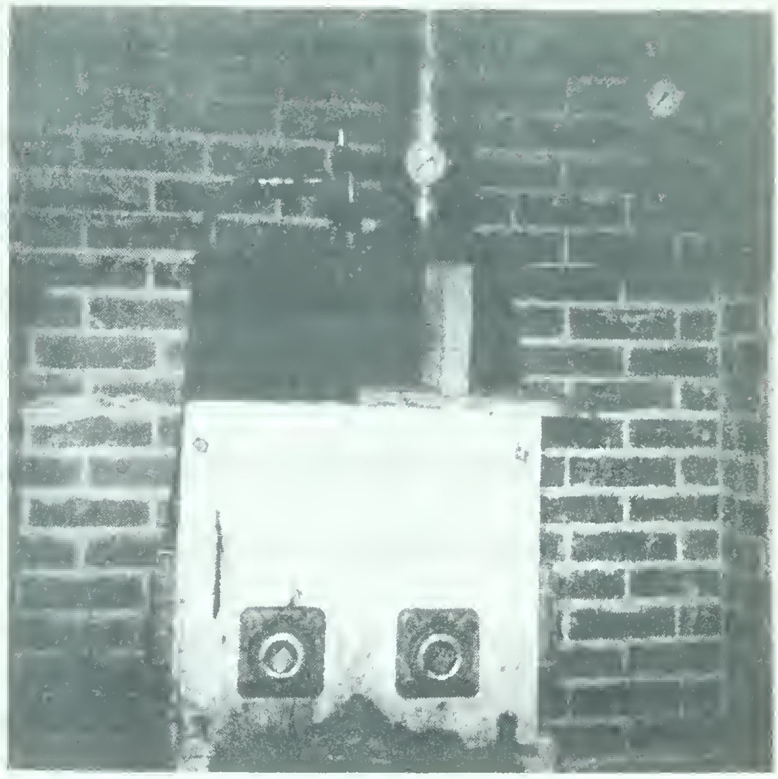
Specific Gravity @ 60° F. - 1.0291	A.P.I. - 6.0
Flash Point C.O.C. 425 + $^{\circ}$F.	
Penetration @ 77° F. (100 gr. 5 sec.) 153	
Ductility @ 77° F. (5 cm./min.) 100+	
Loss on Heating @ 325° F. (50 gr. 5 hrs.) 1-%	
Penetration after L.O.H. test, % of original penetration 70+	
Soluble in CCl_4 99.8 + %	

PLATE 1



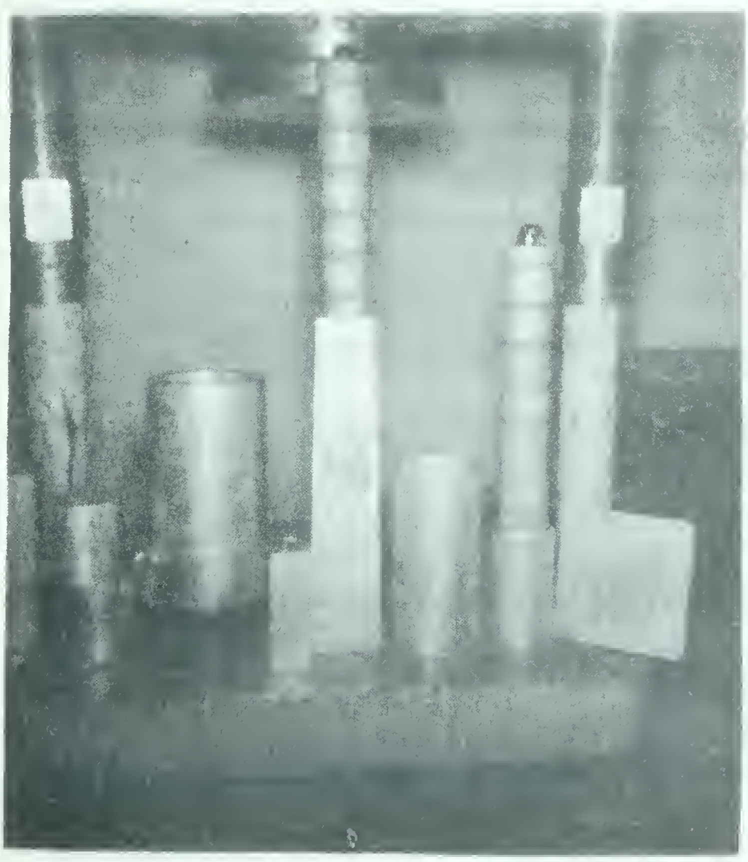
1 A

University of Alberta compaction apparatus



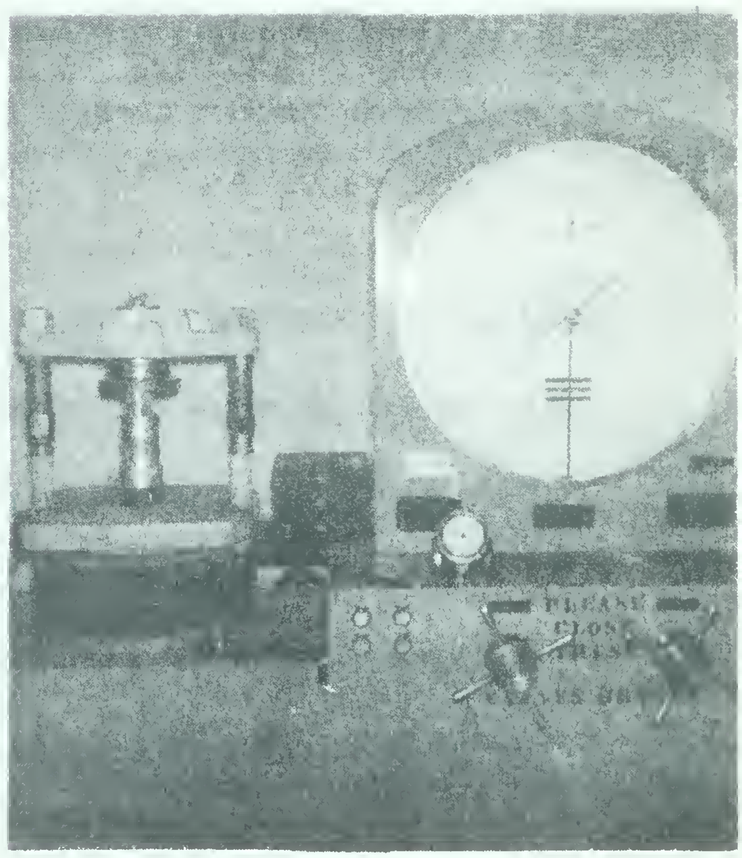
1 B

Pug-mill with foam asphalt nozzle



1C

Hubbard-Field compaction and extrusion apparatus



1D

Hubbard-Field extrusion test in progress

mould. The energies were applied by adjusting the height of fall of a five-pound sliding piston so that the necessary amount was obtained at an even number of blows. For the simulated Standard and Modified Proctor compaction the blows imparted to each end of the specimen were five and twenty, respectively.

Twelve samples of each combination of ten, twelve, fourteen, and sixteen per cent moisture contents (using distilled water) with four, six, and eight per cent asphalt contents, were moulded by the lower compactive effort. For a two-inch diameter by two-inch high specimen, this energy is forty-five foot-pounds. These samples were made from an aerated mixture which had been subjected to twenty-four hours of oven drying at 110° F.

The same combinations of moisture and asphalt contents were used in the preparation of samples to the higher compactive effort, two hundred and five foot-pounds, with ten specimens moulded per combination. One-half of these specimens were moulded immediately after mixing and the remainder were compacted after a twenty-four hour 110° F. aeration period.

Statically compacted specimens. The Hubbard-Field method of specimen preparation was next employed in the investigation. The procedures followed were those of the ASTM Designation D915-47T, "Tentative Method of Testing Soil-Bituminous Mixtures." This portion of the testing program utilized the pug-mill apparatus (Plate 1B) for mechanical mixing. An MC-O asphalt was mechanically mixed with

the moist soil and a 150-200 penetration asphalt cement was used in the foaming process.

The soil moisture contents used in the mechanically mixed trial batches, from which statically compacted specimens were moulded, were eight, ten, twelve, and fourteen per cent. Asphalt percentages were six and eight for the MC-O and five per cent for the 150-200 AC. These asphalt percentages were used with each of the four soil moisture contents. The compaction apparatus for the Hubbard-Field method is shown in Plates 1C and 1D.

III. CURING AND SOAKING OF SPECIMENS

Each sample, when extruded from the mould, was measured for height to ascertain whether it was within the specified limits. Once this condition was met, a record was made of its diameter and weight.

No curing period was applied to those specimens which were moulded to the lower compactive effort. After moulding the oven dried mix, one-half of the number were subjected to the unconfined compression test and the remainder was soaked by the ASTM method.

The samples compacted to the higher compactive effort were moulded at two different times, immediately after mixing and after twenty-four hours of oven drying at 100° F. All wet compacted samples were cured at room temperature for seven days. At the end of this air curing period one-half were strength tested and the other half subjected to seven days of soaking. Of the dry compacted samples, one-half were immediately strength tested and the other half were soaked for

for expansion and absorption determinations.

The Hubbard-Field samples were divided into two sets; one set for the seven-day soaking test and one for seven-day air curing.

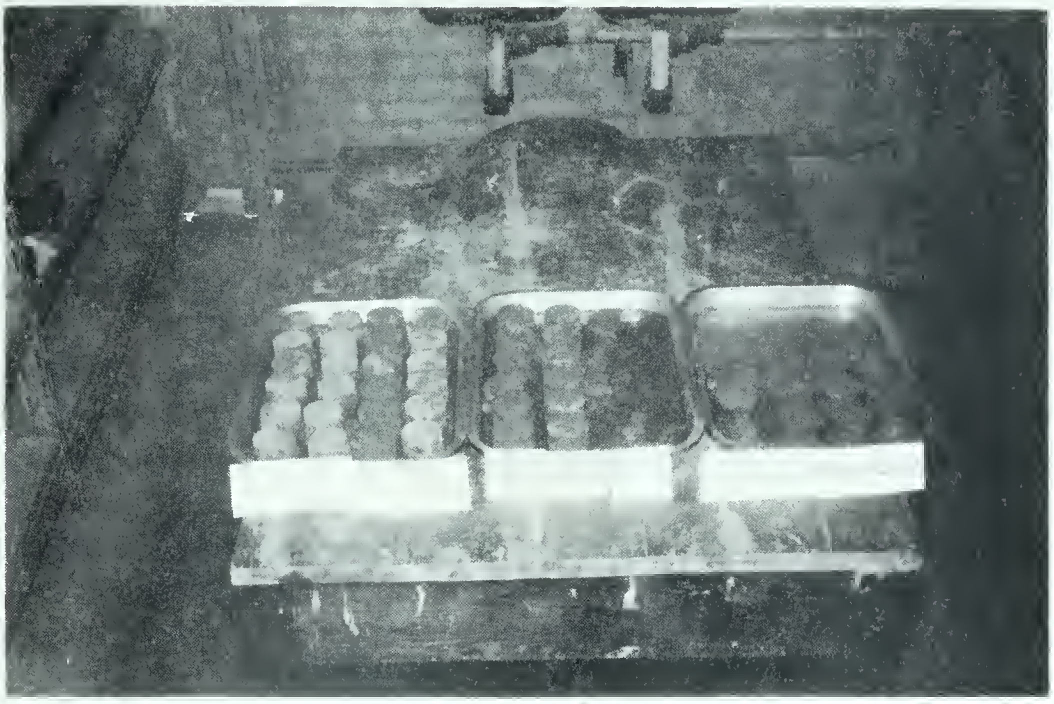
IV. TESTING PROCEDURES AND APPARATUS

Total volatile contents. The percentage of total volatiles in a mixture was determined by the procedure in Tentative Methods of Test for Moisture--Density Relations of Soils, ASTM Designation D698-57T. The samples were placed in an oven having a temperature of $110 \pm 5^{\circ}$ C and were allowed to dry for twenty-four hours.

Absorption and expansion. The water absorption and expansion tests were performed in the moist room. The ASTM standards require a temperature between 65 and 80° F., and a relative humidity of at least 90 per cent. The bottom of the specimen, as tamped, was placed downward during the test. The specimens were placed in a flat-bottomed pan and tap water was added so that the water level was one inch above the bottom of the specimens. This level was maintained for the seven-day soaking period, at the end of which the specimens were quick-blotted to remove free moisture from the surface, weighed, and measured for average bottom diameters. Plate 2A shows specimens in the soaking pans and the equations for absorption and expansion calculations are contained in Appendix B.

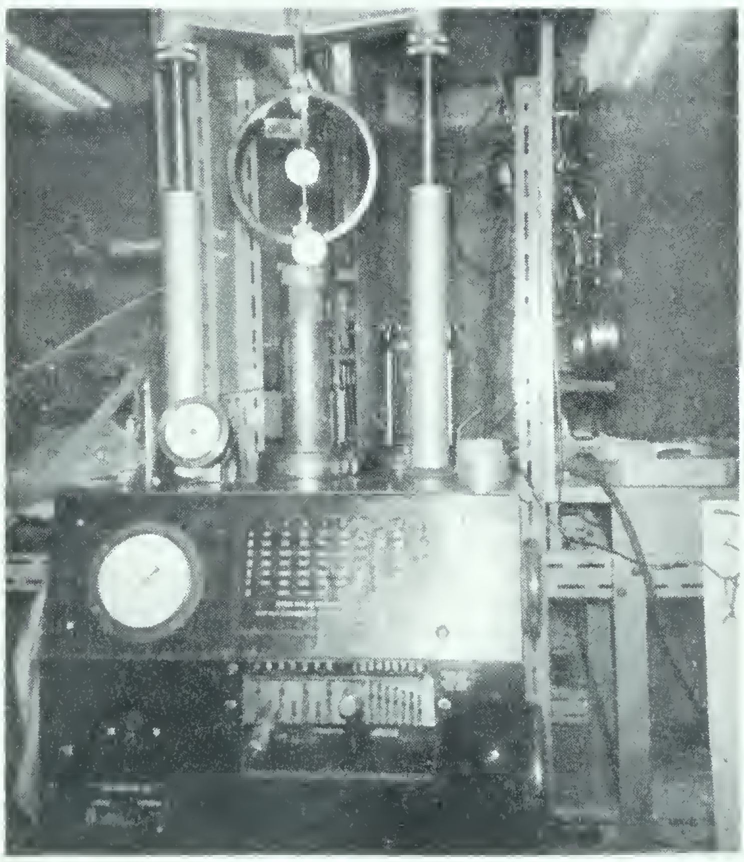
Compression strength tests. All strength tests, with the exception of Hubbard-Field extrusion values, were conducted by the unconfined compressive method and, with a few exceptions, the constant strain

PLATE 2



2 A

Samples in soaking pans



2 B

Farnell compression tester

apparatus shown in Plate 2B was used. Failure loads only, were recorded. The rate of strain employed was 0.08 inches per minute.

Hubbard-Field extrusion. The method of Hubbard-Field extrusion in this investigation has been a combination of ASTM designations D915-47T and D1138-52. This was necessary as the available testing ring and testing plunger were for the latter designation, which is the standard method of test for "Resistance to Plastic Flow of Fine-Aggregate Bituminous Mixtures by Means of the Hubbard-Field Apparatus." The 1.998-inch diameter top plunger shown in Figure 2 was used as the testing plunger in lieu of the specified 1.125-inch diameter plunger. Likewise the 1.75-inch diameter testing ring shown in Figure 3 replaced the 1.125-inch diameter one. Other apparatus shown in Figures 2 and 3 conform to ASTM designation D915-47T. The extrusion test procedure forms a part of Appendix A.

HUBBARD-FIELD COMPACTION APPARATUS

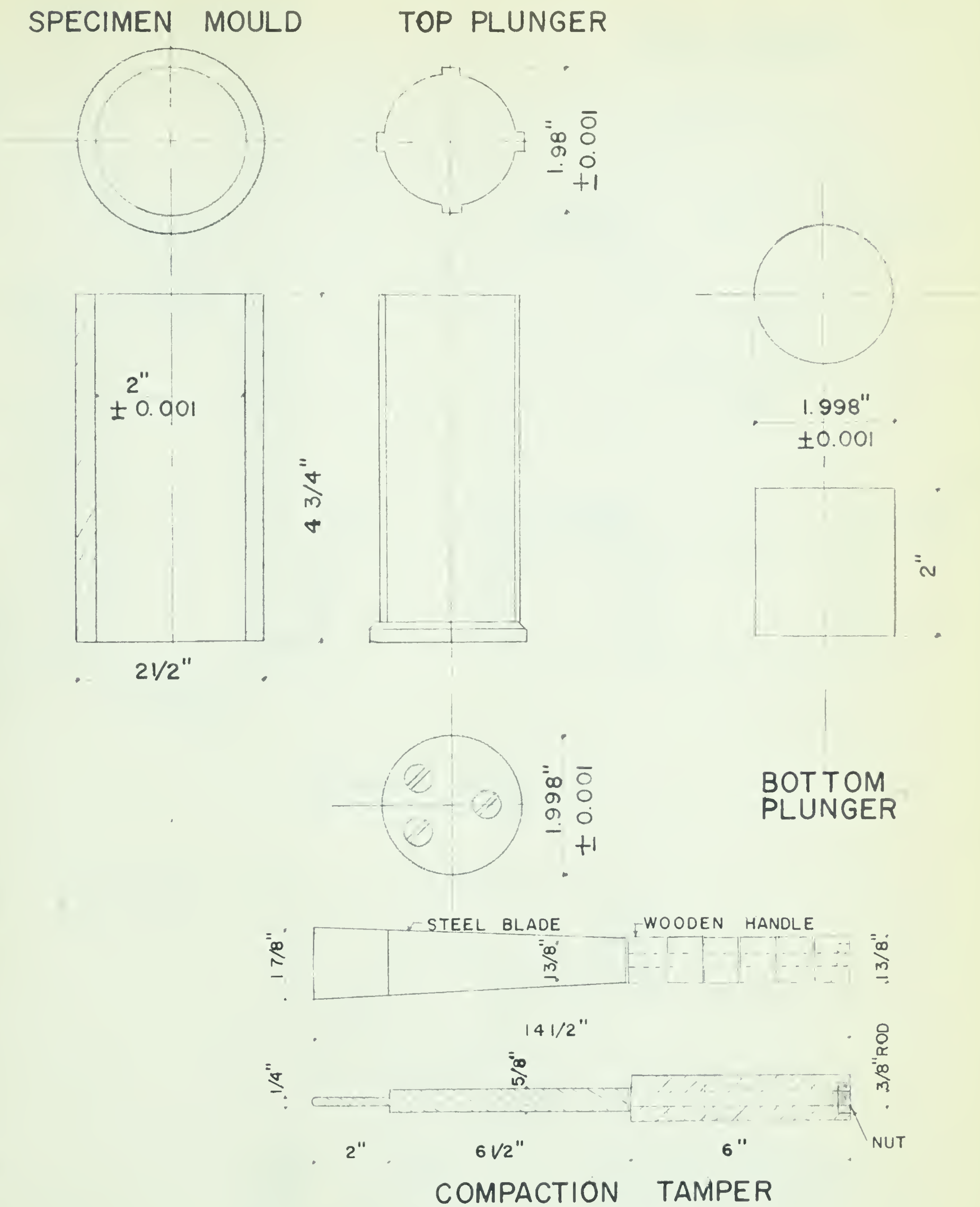


FIGURE 2

HUBBARD — FIELD TESTING APPARATUS

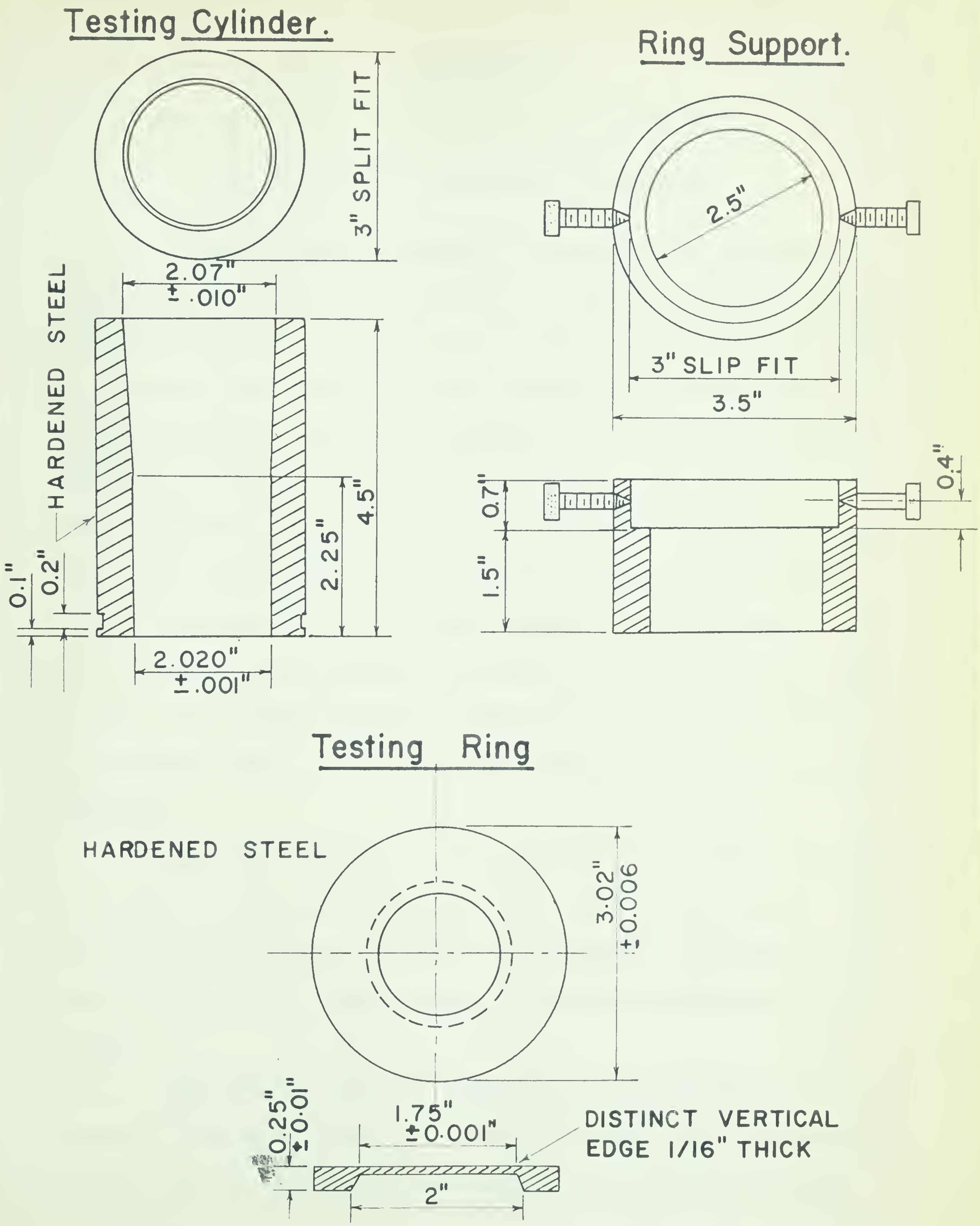


FIGURE 3

CHAPTER V

RESULTS AND DISCUSSION OF RESULTS

I. SIMULATED PROCTOR SPECIMENS

Simulated Standard Proctor compaction. The hand-mixed batches containing four, six, and eight per cent MC-2 asphalt which were subjected to twenty-four hours of oven drying at 110° F. produced low dry densities when specimens were compacted with the University of Alberta apparatus. The range of densities was from seventy-eight to eighty-five pounds per cubic foot with the average for sixty-six specimens, which were strength tested, being eighty-three pounds per cubic foot. This was seventy-five per cent of the Standard Proctor density. The average unconfined compressive strength of these specimens which were compacted at an average total volatile content of one and one-fifth per cent, was thirteen pounds per square inch. Table IV contains the summarized results with average values shown for each group of six specimens.

The equal number of specimens (sixty-six), which were subjected to the ASTM soaking test disintegrated in a relatively short time. After a two- or three-day soaking period it was impossible to salvage a whole specimen for either strength testing, or absorption and expansion calculations.

The aeration period of twenty-four hours appears to have been excessive since the low densities obtained were the result of a scarcity of total volatiles at the time of compaction. The amount of residual

TABLE IV

UNCONFINED COMPRESSIVE STRENGTH RESULTS OF STANDARD PROCTOR SPECIMENS, COMPACTED AFTER 24 HOURS OF OVEN DRYING AT 110° F

Number of Specimens	Total Volatiles after Mixing	% MC-2	Average Unconfined Compressive Strength PSI	Dry Density PCF	Total Volatiles at Compaction
6	11.5	4	14	84	0.35
6	12.8	4	15	83	1.2
6	15.8	4	7	83	1.5
6	9.8	6	17	83	1.6
6	11.7	6	14	83	0.77
6	13.0	6	13	82	1.4
6	16.0	6	9	82	1.2
6	10.0	8	15	84	0.8
6	11.8	8	13	83	1.0
6	13.9	8	13	85	1.3
6	15.6	8	13	78	1.3

asphalt in the mix, for the three percentages used, did not affect strength or dry density. This can be seen from the strength and dry density columns of Table IV.

Simulated Modified Proctor compaction. The oven dried mixtures, which were subjected to two hundred and five foot-pounds compactive energy per specimen, produced an average unconfined compressive strength of fifty-nine pounds per square inch. This ratio of compactive energy to compressive strength was the same as that obtained by the simulated Standard Proctor compaction; namely, forty-five foot-pounds per specimen to thirteen pounds per square inch. The average total volatiles at compaction was similar to that for the simulated Standard Proctor specimens. For thirty-six moulded specimens, the increase in density caused by an increase in compactive effort of approximately four and one-half times, was an average of nine pounds per cubic foot. The resultant dry densities averaged eighty-three per cent of Standard Proctor density and, as in the simulated Standard Proctor compaction, can be attributed to the low value of total volatiles at the time of compaction. Again, the specimens subjected to the soaking test were not sufficiently waterproofed to permit final testing. Table V shows the results for the specimens which were strength tested.

The results of wet specimens moulded to the higher compactive effort are shown in Table VI. These values were used in the preparation of Figure 4 for four per cent MC-2, and, the applicable MC-2 curves in Figures 5 and 6 for six and eight per cent asphalt, respectively.

TABLE V

UNCONFINED COMPRESSIVE STRENGTH RESULTS OF MODIFIED PROCTOR SPECIMENS, COMPACTED AFTER 24 HOURS OF OVEN DRYING AT 110° F

Number of Specimens	Total Volatiles after Mixing	% MC-2	Average Unconfined Compressive Strength PSI	DRY Density PCF	Total Volatiles at Compaction
3	9.7	4	49	95	0.32
3	10.8	4	56	93	0.48
3	13.2	4	67	92	1.2
3	15.9	4	47	92	1.2
3	10.0	6	59	93	0.55
3	11.4	6	53	90	1.2
3	13.7	6	68	90	1.2
3	16.2	6	64	91	1.2
3	9.4	8	55	93	0.55
3	11.9	8	59	90	1.3
3	13.9	8	62	90	1.4
3	16.2	8	67	90	1.5

TABLE

UNCONFINED COMPRESSIVE STRENGTH, % EXPANSION, AND % ABSORPTION OF MODIFIED PROCTOR SPECIMENS, COMPACTED AT MIXING TIME

% MC	Number of Specimens	7 DAY AIR CURE: Total Volatiles at Compaction.	7 DAY AIR CURE: Wet Density	7 DAY AIR CURE: Dry Density	7 DAY AIR CURE: Average qu	7 DAY AIR CURE & 7 DAY SOAKING: Average qu	7 DAY AIR CURE & 7 DAY SOAKING: w %	7 DAY AIR CURE & 7 DAY SOAKING: % Volume Expansion	7 DAY AIR CURE & 7 DAY SOAKING: % Absorption	7 DAY AIR CURE & 7 DAY SOAKING: Average Total Volatiles
4	2	9.7	120	116	331	7	20	15.0	16.2	
6	2	10.0	117	113	242	9	18	12.8	14.4	9.7
8	2	9.4	115	110	127	17	14	10.0	8.5	
4	2	10.8	120	117	301	15	18	12.6	13.0	
6	2	11.4	114	111	175	17	14	6.7	9.7	11.4
8	2	11.9	109	104	77	20	12	5.4	7.3	
4	2	13.2	115	111	202	8	18	9.0	13.9	
6	2	13.7	109	105	130	7	16	7.5	11.9	13.6
8	2	13.9	111	102	73	12	14	5.0	8.9	
4	2	15.9	117	105	191	8	18	3.0	14.4	
6	2	16.2	115	100	108	9	17	3.0	13.0	16.1
8	2	16.2	109	98	77	7	16	3.0	11.3	

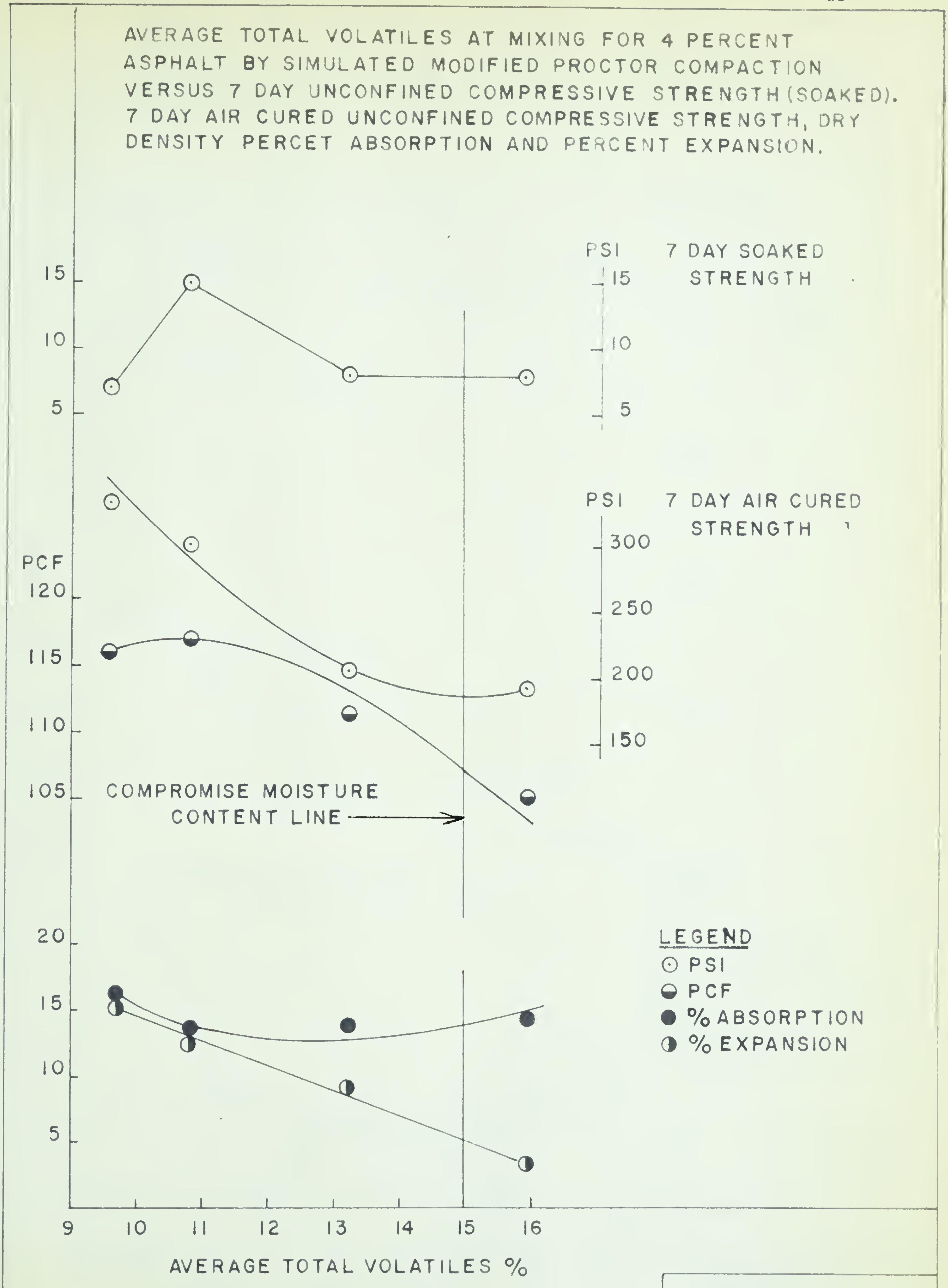
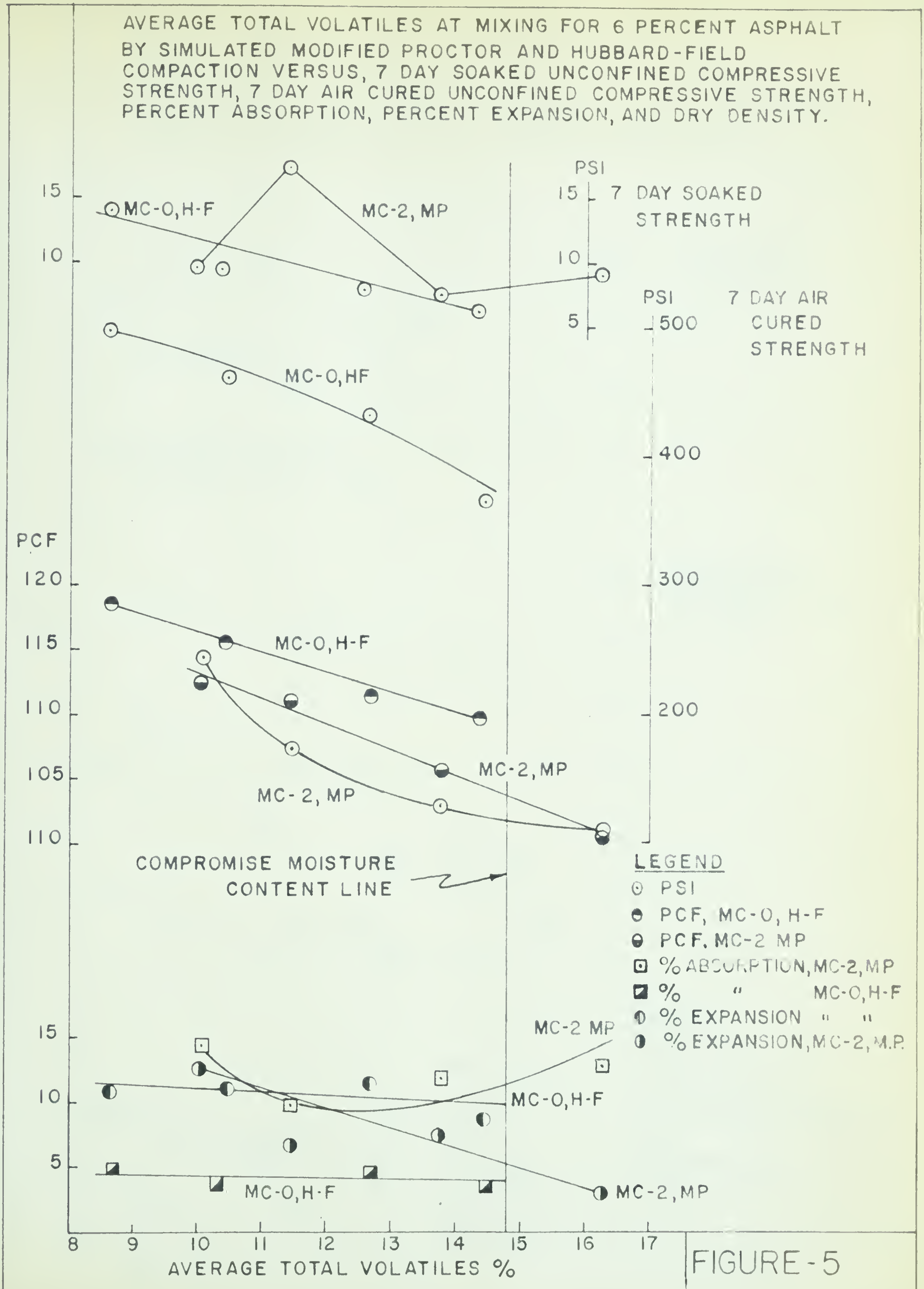

AVERAGE TOTAL VOLATILES AT MIXING FOR 4 PERCENT ASPHALT BY SIMULATED MODIFIED PROCTOR COMPACTION VERSUS 7 DAY UNCONFINED COMPRESSIVE STRENGTH (SOAKED). 7 DAY AIR CURED UNCONFINED COMPRESSIVE STRENGTH, DRY DENSITY PERCET ABSORPTION AND PERCENT EXPANSION.
PSI
7 DAY SOAKED STRENGTH
15
10
5
PSI
7 DAY AIR CURED STRENGTH
300
250
200
150
PCF
120
115
110
105
COMPROMISE MOISTURE CONTENT LINE
20
15
10
5
LEGEND
PSI
PCF
% ABSORPTION
% EXPANSION
9
10
11
12
13
14
15
16
AVERAGE TOTAL VOLATILES %

FIGURE 4.



AVERAGE TOTAL VOLATILES AT MIXING FOR 6 PERCENT ASPHALT BY SIMULATED MODIFIED PROCTOR AND HUBBARD-FIELD COMPACTION VERSUS, 7 DAY SOAKED UNCONFINED COMPRESSIVE STRENGTH, 7 DAY AIR CURED UNCONFINED COMPRESSIVE STRENGTH, PERCENT ABSORPTION, PERCENT EXPANSION, AND DRY DENSITY.
PSI
7 DAY SOAKED STRENGTH
PSI
7 DAY AIR CURED STRENGTH
PCF
MC-0, H-F
MC-2, MP
MC-0, HF
COMPROMISE MOISTURE CONTENT LINE
LEGEND
PSI
PCF, MC-0, H-F
PCF, MC-2 MP
% ABSORPTION, MC-2, MP
% " MC-0, H-F
% EXPANSION " "
% EXPANSION, MC-2, M.P.
AVERAGE TOTAL VOLATILES %

FIGURE - 5

AVERAGE TOTAL VOLATILES AT MIXING FOR 8 PERCENT ASPHALT BY SIMULATED MODIFIED PROCTOR AND HUBBARD-FIELD COMPACTION VERSUS 7 DAY SOAKED UNCONFINED COMPRESSIVE STRENGTH, 7 DAY AIR CURED UNCONFINED COMPRESSIVE STRENGTH, DRY DENSITY, PERCENT ABSORPTION AND PERCENT EXPANSION.

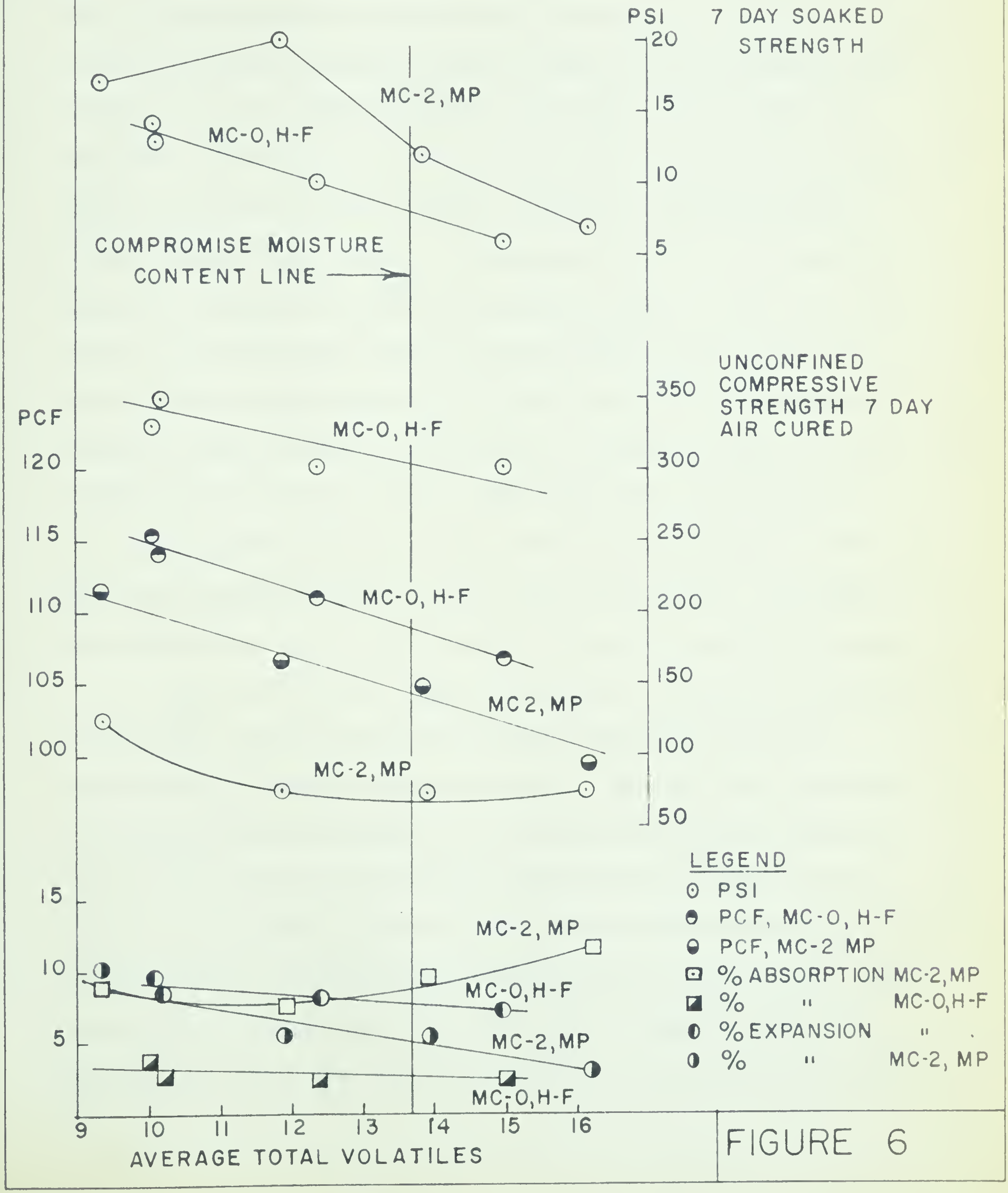


FIGURE 6

As the optimum moisture content for the soil alone by the Modified Proctor compaction method was twelve and three-tenths per cent and the corresponding dry density was 121.5 pounds per cubic foot, it can be seen from the dry density column of Table VI that Modified Proctor densities were not achieved with the University of Alberta apparatus compactive effort used. The dry density values tabulated are for the soil only, but even when the asphalt residual is added the Modified Proctor density is not reached. Considering the four per cent MC-2 specimens compacted at a total volatiles percentage of nine and seven-tenths, the two and nine-tenths per cent residue increases the specimen densities to approximately two pounds per cubic foot less than the Modified Proctor density for the soil only. Hence the effect of the two-inch diameter mould is realized. This effect can be rationalized to the confining influence of the mould and the relatively tight fit of the base post and end post driven by the compaction hammer. The tight fit retards air escape from the mixture during the compaction process.

The vertical line of Figure 4, labelled "Compromise Moisture Content Line," was not obtained by mathematical calculations as explained in the Literature Review Section of Chapter II but was chosen at fourteen and nine-tenths per cent average total volatiles to intersect the expansion curve at the maximum allowable value of five per cent, and thus the absorption criterion was exceeded by one hundred per cent. The intersection of the CMC line with the curves for dry density, seven-day air cured strength, and seven-day soaked strength provides the datum values used in the calculation of "per cent deviation from datum"

shown in Table VII. The same applies to the MC-2 of Figures 5 and 6 for the CMC values of fourteen and seven-tenths and thirteen and seven-tenths per cent total volatiles, respectively. These CMC values were also chosen using the maximum five per cent expansion criterion. The intercepts of dry density and the selected CMC lines in Figures 4, 5, and 6 show dry density values which are approximately four to six per cent below the Standard Proctor density of 111.2 pounds per cubic foot for the soil-water system. Standard Proctor density or greater is one of the objectives in soil bitumen construction.

The CMC values, as selected by the expansion criterion, were approximately the same as the optimum moisture percentage (fifteen and three-tenths) for Standard Proctor compaction. The MC-2 soil bitumen which came the closest to fulfilling both the expansion and absorption criteria was the eight per cent mix which contained eleven and nine-tenths per cent total volatiles at compaction. These percentages were five and four-tenths expansion, based on the ASTM diameter change formula in Appendix B, and seven and three-tenths water absorption, based on the dry weight of the soil. This mix also produced the highest soaked unconfined compressive strength, twenty pounds per square inch. With increasing total volatiles at compaction the expansion percentages decreased but accompanying this desirable property were the undesirable ones of absorption increase, soaked strength decrease, and dry density decrease. Table VI also shows that as the total volatiles increased from eleven and nine-tenths per cent for the

TABLE VII

COMPROMISE MOISTURE* CONTENT CALCULATIONS;

SIMULATED MODIFIED PROCTOR SPECIMENS, MOULDED IMMEDIATELY

AFTER MIXING, CURED SEVEN DAYS AND

SOAKED 7 DAYS

Property	% MC -2	Datum Value	Properties for Average Total Volatiles at Compaction.				% Deviation from Datum.			
			9.7	11.4	13.6	16.1	9.7	11.4	13.6	16.1
7 day cure qu[1]	4	190	331	301	202	191	74	69	6	0
	6	128	242	175	130	108	89	37	2	16
	8	73	127	77	73	77	74	5	0	5
Dry Density PCF	4	103	116	117	111	105	13	14	8	2
	6	104	113	111	105	100	9	7	1	4
	8	104	110	104	102	98	6	0	2	6
7 day cure ≠ 7 day soaked qu[1]	4	8	7	15	8	8	13	87	0	0
	6	8	9	17	7	9	12	112	12	12
	8	13	17	20	12	7	31	54	8	46
% Deviation Totals	4						100	170	14	2
	6						110	156	15	32
	8						111	59	10	59

*Total Volatiles

[1]qu - Unconfined compressive strength in PSI.

eight per cent asphalt, the dry densities decreased and the seven-day air-cured strengths remained relatively constant.

As all cylindrical specimens moulded had a height to diameter ratio of unity the strengths shown in the tables are approximately fifteen per cent too great (2) due to specimen end restraint during testing. Hence the per cent deviation from datum values in Table VII which are partly based on strengths have not been corrected, but are relative one to another. These deviations have been plotted against total volatiles at compaction in Figure 7, where the minimum of each curve occurs at the selected CMC value, to show the effect of changes in volatiles for the three asphalt contents used.

Thus in the testing of simulated Modified Proctor and Standard Proctor specimens, for the asphalt and percentages used, by the ASTM soaking method no soil bitumen mix met the expansion-absorption criteria. When the expansion was less than five per cent the absorption was greater than seven per cent and the dry density was less than Standard Proctor density. Neither did any of the mixes conform to Winterkorn's (9) seventy-five pounds per square inch wet strength requirement, but possibly this was due to the low densities obtained and to lower asphalt residues than those which he recommends. Those cylindrical specimens formed from the wet mixtures displayed better stabilized properties but still did not meet all the design specifications.

II. HUBBARD-FIELD SPECIMENS

Absorption, expansion, and densities. The plots of per cent

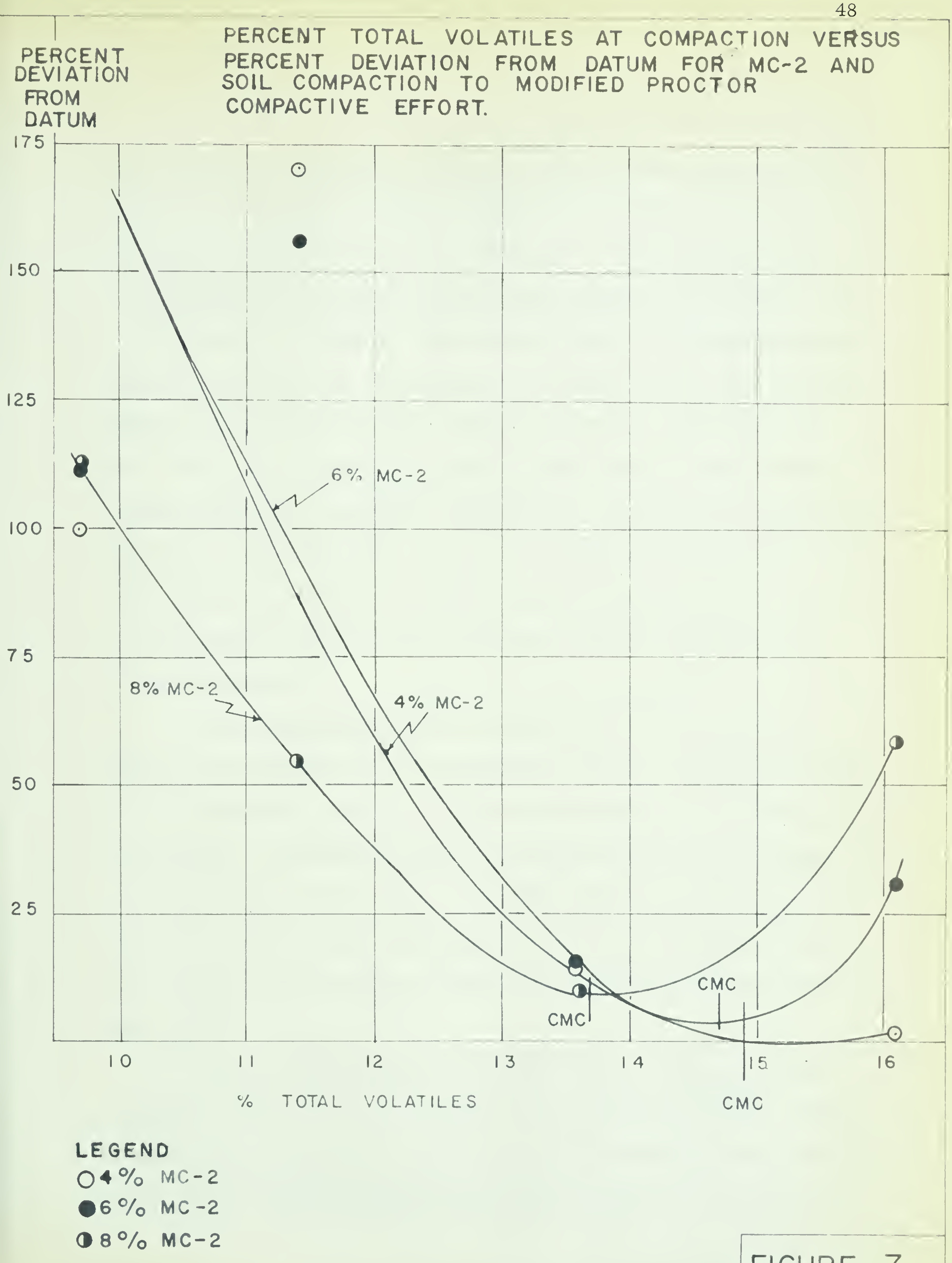

PERCENT TOTAL VOLATILES AT COMPACTION VERSUS PERCENT DEVIATION FROM DATUM FOR MC-2 AND SOIL COMPACTION TO MODIFIED PROCTOR COMPACTIVE EFFORT.
PERCENT DEVIATION FROM DATUM
175
150
125
100
75
50
25
6% MC-2
4% MC-2
8% MC-2
CMC
CMC
CMC
10
11
12
13
14
15
16
% TOTAL VOLATILES
LEGEND
4% MC-2
6% MC-2
8% MC-2

FIGURE 7

total volatiles at compaction versus per cent absorption and per cent expansion for six per cent MC-O, eight per cent MC-O, and five per cent 150-200 penetration AC are in Figure 8. The absorption values are all within the seven per cent allowable except for the five per cent AC when the total volatiles, water in this instance, was approximately less than nine per cent. The eight per cent MC-O curve (four and five-tenths per cent residue) is below that of the six per cent (three and four-tenths per cent residue), which signifies that the larger asphalt residual decreases absorption. When the AC was introduced to the soil as a foam the asphalt distribution was not as uniform as in the MC-O mixes. This most likely accounts for the AC curve crossing the MC-O curves and increasing to a value above the design criterion at the nine per cent total volatiles.

In the expansion portion of Figure 8 the MC-O curves are relative to one another as in the absorption plot and the same trend for the AC is apparent, rising at a rapid rate when the total volatiles are less than ten. However, all expansion values for the Hubbard-Field specimens were greater than the allowable maximum of five per cent. The MC-O expansion and absorption curves are also shown on Figures 5 and 6 along with the curves for the simulated Modified Proctor MC-2 test results.

On these two Figures it is revealed that the Hubbard-Field compaction method produced greater dry densities and greater seven-day air-cured strengths than did the simulated Modified Proctor method. The increase in dry density was four to five pounds per cubic foot and

GRAPH OF TOTAL VOLATILES AT COMPACTION FOR HUBBARD-FIELD SPECIMEN VERSUS

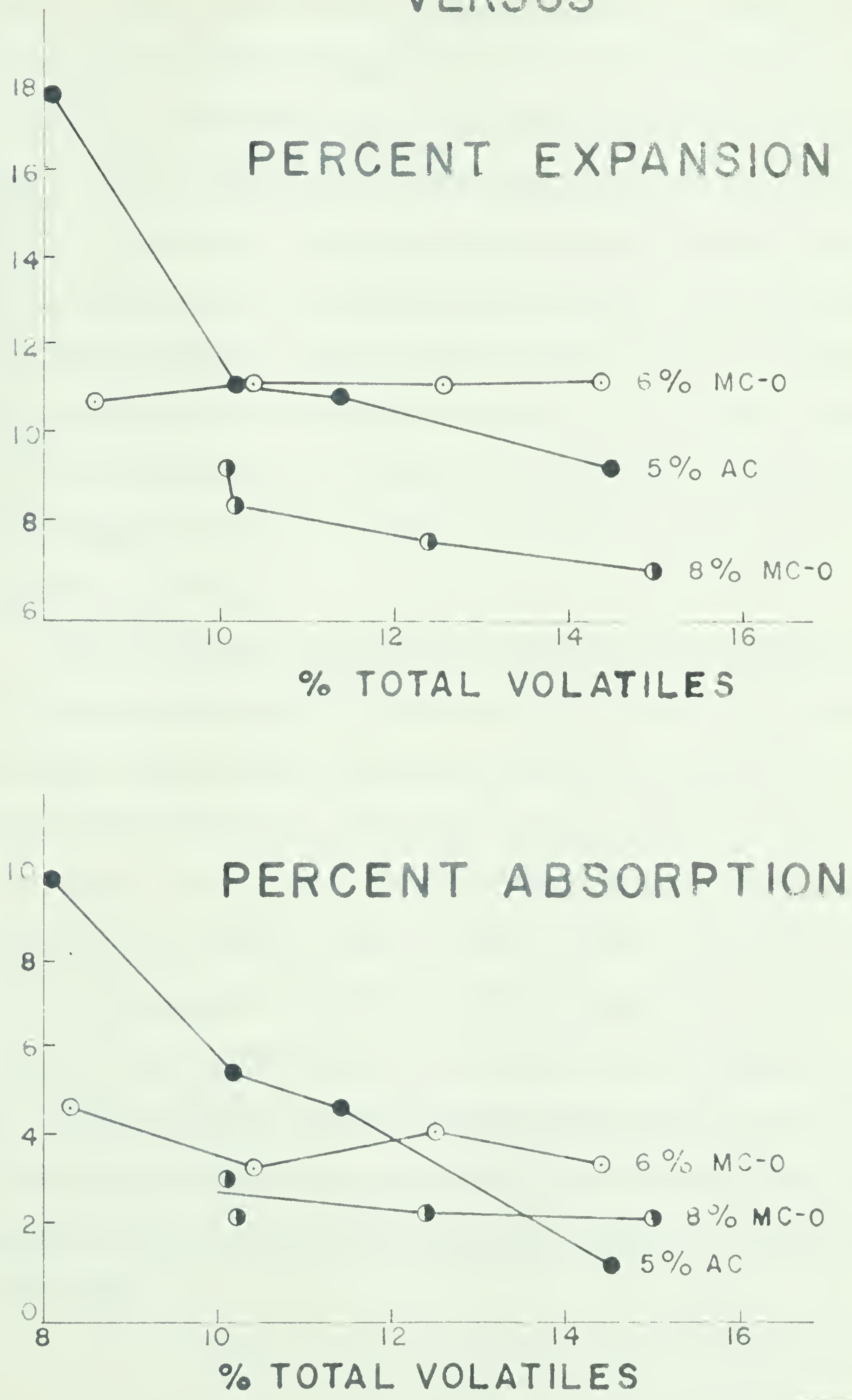


FIGURE 8

the resulting increase in seven-day air-cured strength was 225 pounds per square inch. The same dry densities by the two methods produced approximately twice the strength in the air-cured specimens of the Hubbard-Field method than that in the simulated Modified Proctor method. Here the influence of asphalt distribution caused by mechanical mixing is exemplified. The soil bitumen displayed greater cohesion with better distribution of asphalt and the mechanically-mixed trial batches with the highest asphalt residue came closest to simultaneously satisfying expansion and absorption criteria. Because the methods of specimen treatment prior to soaking were different, the seven-day soaked strengths of Figures 5 and 6 are applicable only to the asphalts and methods employed.

The resultant densities by the Hubbard-Field method were affected by the close-machined tolerances of the compaction apparatus. At the higher total volatiles content for the MC-O specimens, the air within the specimen was at a pressure greater than atmospheric. When the specimens were extruded from the mould small bubbles appeared on the surface and could be seen to burst. Hence, as in the compaction methods employing the University of Alberta apparatus, the densities are lowered by the confining characteristics of the compaction equipment. The dry densities by the Hubbard-Field method were all in excess of ninety-five per cent Standard Proctor density, and most exceeded the ninety-five per cent Modified Proctor value of 115 pounds per cubic foot.

Extrusion values. The Hubbard-Field seven-day soaked extrusion values are shown on Figure 9 plotted against per cent total volatiles at compaction. The waterproofing characteristic of increasing asphalt residue is displayed by the location of the eight per cent MC-O curve above the six per cent MC-O curve. The low extrusion values of the five per cent AC, which also had the poorest absorption and expansion characteristics at low total volatile percentages, can be attributed to the previously referred non-uniform asphalt distribution. None of the soaked extrusion values qualified for the design criterion of four hundred pounds. The application of the AC foam to the moist soil took place over a period of only a few seconds. It is possible that during this short period insufficient surface area of soil was in contact with the foam. The foam bubbles could then unite upon contact with one another to form larger globules in lieu of uniting with soil particles. This would account for the poor asphalt distribution obtained in comparison to the mechanically mixed MC-O and the hand-mixed MC-2 batches.

Better waterproofing properties with the silty clay and 150-200 penetration AC might be obtained in the foamed process by varying the steam and asphalt pressures, by a higher pug mill shaft speed, or by intermittent injection of the foam. The latter development possibly would simulate multiple-pass construction in the field.

As the seven-day air-cured Hubbard-Field specimens all exceeded the one thousand pound extrusion criterion, no plot was made of the values versus per cent total volatiles at compaction. The test

AVERAGE HUBBARD-FIELD EXTRUSION VALUES VERSUS TOTAL VOLATILES AT COMPACTION, FOR 7 DAY SOAKED SAMPLES

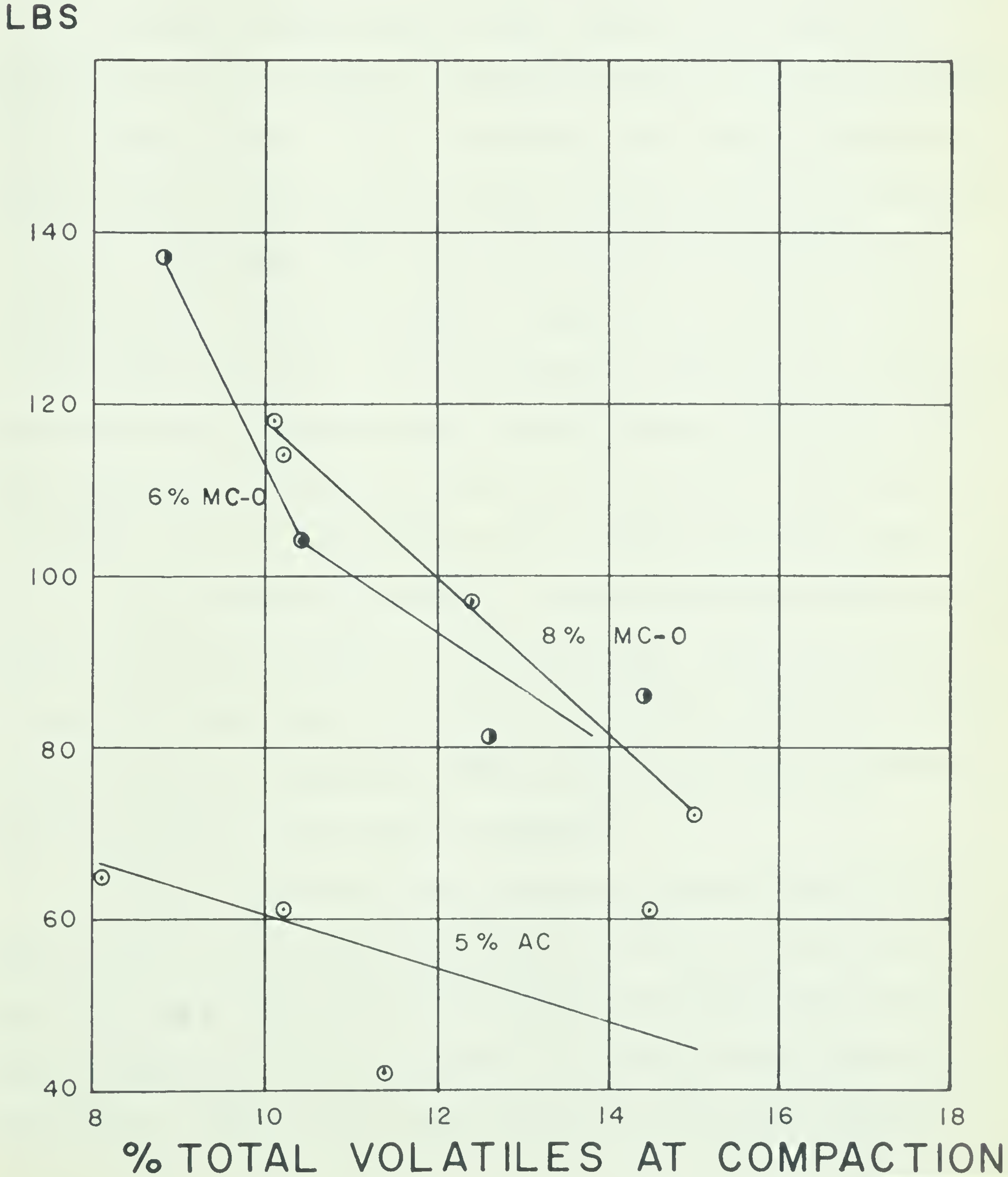


FIGURE 9

results by the Hubbard-Field method are contained in Table VIII where the values shown are averages for three specimens. Two exceptions to this averaging are the columns of "Total Volatiles at Compaction" and "Unconfined Compressive Strength" which are single determinations.

In Table VIII the highest "Total Volatiles at Compaction" employed for each percentage of asphalt residue gave the best expansion and absorption results. Thus, considering these highest compaction volatiles only, for the apparatus and procedures used, the unconfined compressive strengths which are equivalent to one thousand pounds extrusion for the six per cent MC-O, eight per cent MC-O, and five per cent AC are 143, 121, and 169 pounds per square inch, respectively. The one thousand pound extrusion criterion refers to the seven-day air-cured specimens. Knowles (20) has reported that for a clean sand an unconfined compressive strength of ten to fifteen pounds per square inch was approximately equivalent to a modified Hubbard-Field extrusion value of one thousand pounds. His investigation, however, employed specimens of a different size, different compaction, different curing, a different extrusion ring size, a different rate of testing, and different materials to those used in this investigation.

For the seven-day soaked specimens, again using the highest total volatiles at compaction which were synonymous with the best expansion--absorption values, the average soaked extrusion value for the two types of asphalt and three percentages of asphalt residual was seventy-four pounds. This was only eighteen per cent of the four hundred

TABLE VIII

RESULTS OF HUBBARD-FIELD TESTING BY ASTM DESIGNATION D915-47T[1]

Asphalt type and % residue	Number[2] of Specimens	Total Volatiles at Compaction	Dry Density PCF	7 DAY AIR CURE			7 DAY SOAKING		
				Extrusion Value lbs.	Unconfined Compressive Strength PSI	% Voids at Compaction	% Expansion	% Absorption	Extrusion Value lbs.
MC-0	7	8.6	118	4880	495	7.3	11.0	4.8	137
	7	10.4	115	5130	459	5.6	11.4	3.4	104
3.4	7	12.6	111	5180	430	4.6	11.4	4.3	81
	7	14.4	109	5150	360	1.9	9.5	3.5	86
	7	10.1	125	2920	329	3.2	9.5	3.2	118
MC-0	7	10.2	126	2820	350	4.1	8.6	2.3	114
4.5	7	12.4	123	2990	302	2.8	7.8	2.4	97
	7	15.0	122	3640	301	0.3	7.1	2.3	72
150-200	7	8.1	117	9350	530	5.1	18.0	10.1	61
	7	10.2	114	8670	615	5.4	11.4	5.6	42
AC	7	11.4	111	9000	730	1.2	11.1	4.8	61
5.0	7	14.5	108	7400	440	1.9	9.5	1.6	65

[1] Test plunger and testing ring conformed to ASTM designation D1138-52

[2] Three specimens for 7 day air cure extrusion test, three specimens for 7 day soaking test, and one specimen for 7 day air cure unconfined strength test.

pound criterion.

Per cent voids at compaction. Figure 10 contains the curves for per cent air voids versus total volatiles at compaction. The minimum air voids were obtained when the total volatiles were between fourteen and sixteen per cent. With decreasing total volatiles at compaction, an increase in per cent air voids was indicated for the MC-O curves. The discontinuous curve for the five per cent AC was possibly caused by the non-uniformity of asphalt distribution compared to the MC-O mixtures. The air voids, over the total volatiles range of twelve and three-tenths to fifteen and three-tenths per cent, were within those limits which apply to a sheet-asphalt design by the Hubbard-Field method. These percentages of total volatiles are cited as they are the optimum moisture contents for the soil alone when compacted by the Modified Proctor and Standard Proctor methods.

III. GENERAL DISCUSSION OF RESULTS

Methods of mixing and mixing water contents. The process of mixing likely establishes the "basic structural system" (10) of the mixture. Initially in the mixing process, the soil is in the continuous phase which changes to a discontinuous one as soil agglomerates are formed and become coated with asphalt as the cutback asphalt dispersion progresses. When mixing asphalt with a fine-grained soil this agglomerate, a small volume of moist soil which is relatively free of asphalt, formation is the tendency. As only low percentages of asphalt are used

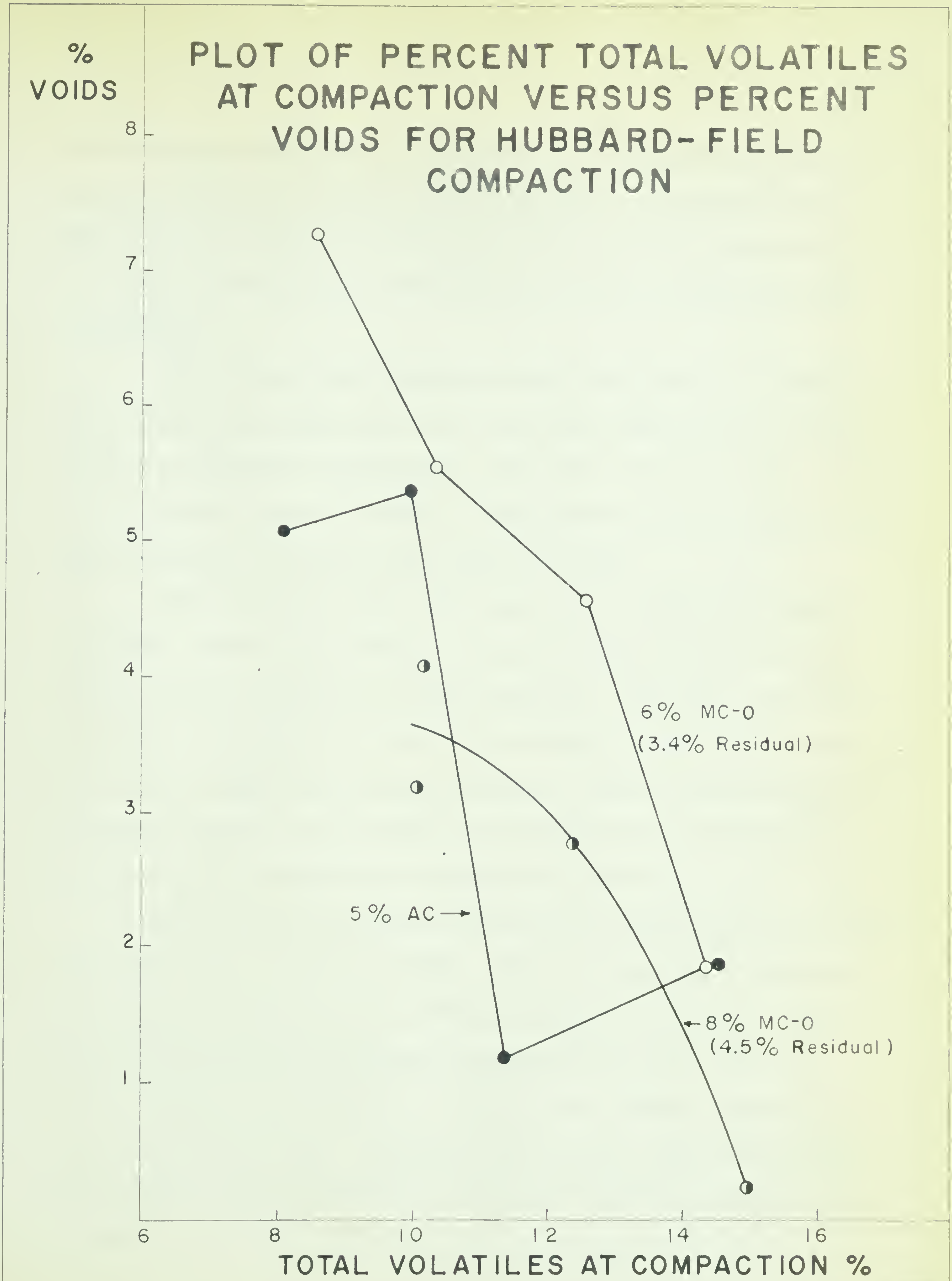

%
VOIDS
PLOT OF PERCENT TOTAL VOLATILES AT COMPACTION VERSUS PERCENT VOIDS FOR HUBBARD-FIELD COMPACTION
8
7
6
5
4
3
2
1
6% MC-0
(3.4% Residual)
5% AC
8% MC-0
(4.5% Residual)
6
8
10
12
14
16
TOTAL VOLATILES AT COMPACTION %

FIGURE 10

in soil bitumen stabilization, it is possible that the asphalt in a mixture is never sufficient to become a continuous phase. The eight per cent MC-O mixtures prepared at the higher moisture contents appeared to be of a more homogeneous nature than other mixtures prepared in this investigation.

The mixing by hand method produced more globules of asphalt, which appeared to occupy space in the specimen without being a continuous film surrounding an agglomerate, than did mechanical mixing. This was not entirely due to the change in mixing methods but partially due to different asphalt viscosities and energies of mixing.

The amount of mixing water appeared to influence expansion, absorption, density, and stability. In general, for both the simulated Modified Proctor and Hubbard-Field specimens, expansion--absorption decreased, dry density decreased, and stability decreased with increasing amounts of total volatiles at compaction. The decreasing expansion-absorption tendency was beneficial as it signified better waterproofing but the decreasing stability was a detrimental property.

Individual soil aggregates affect the final density of the compacted mass much more so than the asphalt. This is caused by the differences in specific gravity and the low asphalt percentage in the mass. Thus the maximum density of the asphalt mixtures should occur when the total lubricant present is nearly the same as the optimum moisture content for the soil alone. Additional water assists asphalt distribution but it should be evaporated before compaction if maximum densities are to result.

<u>Effects of asphalt distribution.</u> By mechanical mixing and Hubbard-Field testing, an increase in asphalt content with constant total volatiles at compaction appeared to decrease stability, expansion, and absorption. The same trend was noted for the simulated Modified Proctor specimens prepared from hand-mixed batches. It would seem that the more intimate the mix, from an asphalt distribution standpoint, the lower the stability, the per cent volume expansion upon soaking, and the per cent water absorbed upon soaking.

When a specimen is placed to soak those regions of the mixture which have not been adequately protected by asphalt absorb the water. The asphalt-soil bond is water sensitive and upon soaking the bond is destroyed as the water finds its way into the asphalt-soil interface.

The outer layer of a soil agglomerate in a stabilized mix loses its natural cohesion when surrounded by an asphalt film. This results in a loss in strength but a waterproofing characteristic is provided. Thick films are required for optimum waterproofing but thin films produce strong cohesion as the "shearing resistance between two solids is inversely proportional to the film thickness." (16) This could be the reason why the maximum stability of the compacted trial mixtures prepared by hand-mixing and mechanical mining did not occur when the asphalt was the most uniformly distributed.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

I. CONCLUSIONS

This thesis has been composed of two main parts: the objectives, general aspects, and mechanics of soil bituminous stabilization; and the testing program. The general aspects and mechanics have dealt with cohesive materials and the testing program has employed the unconfined compressive test and a modified Hubbard-Field test. The investigation has been of too limited a nature to establish definite rules or prove that it would be possible to obtain a laboratory finished product which would satisfy the four principle design criteria set forth in Chapter II. On the basis of the results presented the following conclusions are offered:

1. The specimens, prepared by two compactive efforts from the aerated mixtures, containing four, six, and eight per cent MC-2 asphalt contents and containing an average of one per cent total compaction volatiles, have low density and strength characteristics and exhibit negligible resistance to expansion and absorption. If the aeration period had been shorter the specimens would have exhibited higher dry densities and higher unconfined compressive strengths.

2. A trend shown by the Modified Proctor wet compacted specimens is that, for all three asphalt contents over the range of total volatiles used, the expansion is decreased as the total volatiles are increased. The same applies to the density, the dry strength, and partially to the

absorption which decreases to a minimum value, then increases. The soaked unconfined compressive strength is a maximum when this minimum absorption occurs.

3. For the simulated Modified Proctor wet compacted specimens which progressively contained increased total compaction volatiles, the five per cent expansion requirement is met at a total volatiles content slightly less than the Standard Proctor optimum moisture content for the raw soil.

4. For the silty clay soil at an average water content of thirteen per cent mixed with four, six, and eight per cent MC-2 asphalt, the energy that is required to produce ninety-five to one hundred per cent Standard Proctor density, using the University of Alberta apparatus, is equal to the energy of Modified Proctor compaction.

5. The modified Hubbard-Field specimens containing six and eight per cent MC-O asphalt have good anti-absorptive properties, exceed the allowable expansion by an average of eighty-eight per cent, and have the greatest soaked and air-cured strengths associated with greatest dry density.

6. A modified Hubbard-Field extrusion value of 1000 pounds is equivalent to an unconfined compressive strength of 121 to 169 pounds per square inch. This range of values is applicable to the apparatus, procedures, and materials employed in the work reported herein.

7. The standards of design have been only partially satisfied, so the test results are of little or no value for a soil bitumen construction design and/or specification preparation.

II. RECOMMENDATIONS

Partially from the findings of this investigation and partially from information in the literature, the following recommendations are made:

1. That further research with a typical silty clay soil as a material for stabilization be conducted using those MC and RC asphalts which are recommended for soil bitumen by the Asphalt Institute. This is provided that waterproofing is a more important criterion than stability because, from an economical consideration, the asphalt residual in a cutback asphalt costs approximately twice that of an equivalent weight of Portland cement. However, to stabilize a silty clay soil, containing as much as forty-five per cent silt sizes, the amount of asphalt residual required by weight could be as little as one-half that required when Portland cement is used. Any continued research should employ asphalt contents which provide greater amounts of residue than those used in this investigation, provided the additional residue will allow the formation of soil agglomerates in the mixing process and will coat the agglomerates rather than be uniformly dispersed.

2. That any further research, of the above recommended nature, should take into account physico-chemical property changes in the soil bitumen, and that secondary additives be used to modify such physico-chemical properties as plasticity and cohesion. The secondary additives should be hydrophobic and provide thin films, to which asphalt will readily be attracted, around soil aggomerates.

3. That the foamed asphalt process be further investigated using a silty clay soil with emphasis placed on procuring a more favorable degree of asphalt distribution.

LIST OF REFERENCES

LIST OF REFERENCES

1 Winterkorn, H. F., Science of Soil Stabilization, Highway Research Board, Bulletin 108, 1955.

2 Hvozdanski, J., Laboratory Investigations of Some Variables Influencing Strength of a Silty Clay with a Lime-Pozzolan Additive, Unpublished Master's of Science Thesis, University of Alberta, 1962.

3 Woods, K. B., Highway Engineering Handbook, McGraw-Hill Book Company Inc., Toronto.

4 Csanyi, Ladis H., and Nady, Robert M., The Design of Bituminous Paving Mixtures by a Mortar Theory Using Local Ungraded Asphalts, Proceedings, Association of Asphalt Paving Technologists, 1955.

5 Traxler, Ralph N., Asphalt--Its Composition, Properties and Uses, Reinhold Publishing Corporation, 1961.

6 Csanyi, Ladis H., Foamed Asphalt in Bituminous Paving Mixtures, Highway Research Board Bulletin 160, 1957.

7 Nady, Robert M., and Csanyi, Ladis H., Use of Foamed Asphalt in Soil Stabilization, Proceedings, Highway Research Board, 1958.

8 Ritter, L. J., and Paquette, R. J., Highway Engineering, Ronald Press Company, New York.

9 Winterkorn, H. F., Granulometric and Volumetric Factors in Bituminous Soil Stabilization, Proceedings, Highway Research Board, 1957.

10 Katti, R., Davidson, D. T., and Sheeler, J. B., Water in Cutback Asphalt Stabilization of Soil, Highway Research Board, Bulletin 241, 1959.

11 Hoiberg, Arnold J., and Brown, M., Studies in Stabilization of Fine-Grained Soils with SC-Oils, by the Modified Bearing Test Procedure, Proceedings, Association of Asphalt Paving Technologists, 1952.

12 Michaels, A. S., and Puzinauskas, V., Additives as Aids to Asphalt Stabilization of Fine-grained Soils, Highway Research Board, Bulletin 129, 1956.

13 Wooltorton, F. L. D., Engineering Pedology and Soil Stabilization, Highway Research Board, Bulletin 108, 1955.

14 Curtis, W. E., Application of Foamed Asphalt Process to Bituminous Mixes, Preprint of a paper presented to the Canadian Technical Asphalt Association, November, 1962.

15 Lambe, William T., The Structure of Compacted Clays, Proceedings of the American Society of Civil Engineers, May, 1958.

16 Endersby, V. A., Fundamental Research in Bituminous Soil Stabilization, Proceedings, Highway Research Board, 1942.

17 Andrews, A. C., and Noble, G. G., A Study of Bituminous-Soil Stabilization by Methods of Physical Chemistry, Proceedings, Highway Research Board, 1949.

18 Yoder, E. J., Principles of Pavement Design, John Wiley and Sons, Inc., New York.

19 Herrin, M., Drying Phase of Soil-Asphalt Construction, Highway Research Board, Bulletin 204, 1958.

20 Knowles, J. A., Soil-Asphalt Stabilization with a Lime Additive, Unpublished Master's of Science Thesis, University of Alberta, 1962.

APPENDICES

APPENDIX A

SPECIMEN PREPARATION PROCEDURE, HUBBARD-FIELD COMPACTION PROCEDURE, AND HUBBARD-FIELD EXTRUSION PROCEDURE

APPENDIX A

<u>Specimens compacted by U. of A. apparatus.</u> The procedure for simulated Standard and Modified Proctor density specimens was as follows:

(a) The air dry soil, which contained 2.3 per cent moisture content, was mixed with 10, 12, 14, and 16 per cent water and allowed to soak approximately twelve hours in the moist room.

(b) Prior to the soaking period the complete wet soil mixture was passed through a number four sieve.

(c) After the soaking period the applicable asphalt content, at room temperature, was added to the soil and mixed by hand for four minutes.

(d) Samples were taken for total volatiles determinations.

(e) Specimens, using the "wet" mixture and the Modified Proctor compactive effort, were moulded.

(f) The remaining wet mixture was placed in the oven for a twenty-four hour aeration period with the oven temperature maintained at 110^{o} F.

(g) The oven dried mixture was used to mould "dry" specimens. To keep within the height tolerance of the compacted specimen it was necessary to find the proper weight of loose mix by trial.

A one-inch high temporary support for the forming mould was placed around the two-inch base post. When the mould was placed around the post, a collar for the forming mould was next positioned in

order that the total volume would be sufficient to contain the loose mixture. Fifty per cent of the compactive effort required was then given this one layer of mix. The temporary support for the mould was removed after the first one or two blows. Its purpose was to keep the specimen centered in the mould. The extension to the mould was removed and the mould reversed on the base post in order to complete the compactive effort on the original bottom of the specimen. After compaction the samples were extruded.

Hubbard-Field compaction. A bottom compaction plunger was placed on a base plate and the forming mould was positioned around the plunger. The required amount of mix was placed in the mould. Initial compaction was obtained by twenty-five blows using a 1030 gram tamper. The tamper was allowed to fall freely from a height of six inches above the bottom of the specimen being formed. It was rotated between the application of blows. As the average height of hammer drop was 2.75 inches, this initial compactive effort was 3580 foot-pounds per cubic foot or 13 foot-pounds per specimen.

Final compaction was obtained by means of a testing machine. A top compaction plunger was placed in the mould and a total load of 6000 pounds was applied. The specimen was compressed at a constant rate of one inch per minute, and when the 6000 pounds was reached the load was held for two minutes. The load was then released and the sample extruded.

Two methods of mixing were employed prior to the compaction

of specimens by the Hubbard-Field method. The first method involved the addition to the soil of MC-O as the pug-mill operated. The asphalt, at room temperature, was hand-poured over a period of thirty seconds. At this point the mixing cycle was considered to commence and was allowed to proceed for two and one-half minutes. The percentages of asphalt used were six and eight, each with soil moisture contents of 8, 10, 12, and 14 per cent.

The foamed asphalt process comprised the second mechanical procedure in the Hubbard-Field method of specimen preparation. A five per cent 150-200 penetration AC was chosen as this percentage approximated the asphalt residual of the eight per cent MC-O cutback. The same soil moisture contents were employed, and the two and one-half minutes mixing cycle was used, as in the MC-O hand-pouring method.

The asphalt cement, at a temperature of 350° F. was supplied to the foaming nozzle at a pressure of 30 pounds per square inch gauge. The steam was applied to the nozzle at a pressure of 50 pounds per square inch gauge immediately prior to the opening of the asphalt valve. The pug-mill was put in operation just before the introduction of the foamed asphalt. This was essential to facilitate asphalt distribution as the foam was produced for only a few (five to ten) seconds of the mixing cycle.

<u>Hubbard-Field extrusion.</u> For the extrusion test the procedure, for both air-cured and soaked specimens, was as follows:

(a) The ring support, testing ring, and testing cylinder were

assembled.

(b) Specimens for testing were weighed, measured for height, and if necessary measured for average bottom diameter.

(c) A specimen was placed in the testing cylinder. If it was a soaked specimen the bottom face during soaking was kept downward during the test, and if necessary it was gradually forced into the test cylinder to contact the testing ring by use of the compaction plunger.

(d) The test plunger was placed on top of the specimen.

(e) The test assembly was centered on the platform of the testing machine.

(f) Load was applied to the specimen through the plunger which moved at a constant rate of one inch per minute.

APPENDIX B

EQUATIONS FOR ABSORPTION AND EXPANSION CALCULATIONS

APPENDIX B

$$\text{Per cent water absorption} = \frac{W_2 - W_1}{W_d}$$

W_1 = weight before absorption

W_2 = weight after absorption

W_d = calculated weight of dry soil in specimen

$$\text{Per cent expansion} = \frac{(D_2^3 - D_1^3)(100)}{D_1^3}$$

D_1 = diameter before absorption

D_2 = average diameter of bottom of specimen after absorption

APPENDIX C

PRELIMINARY TESTING

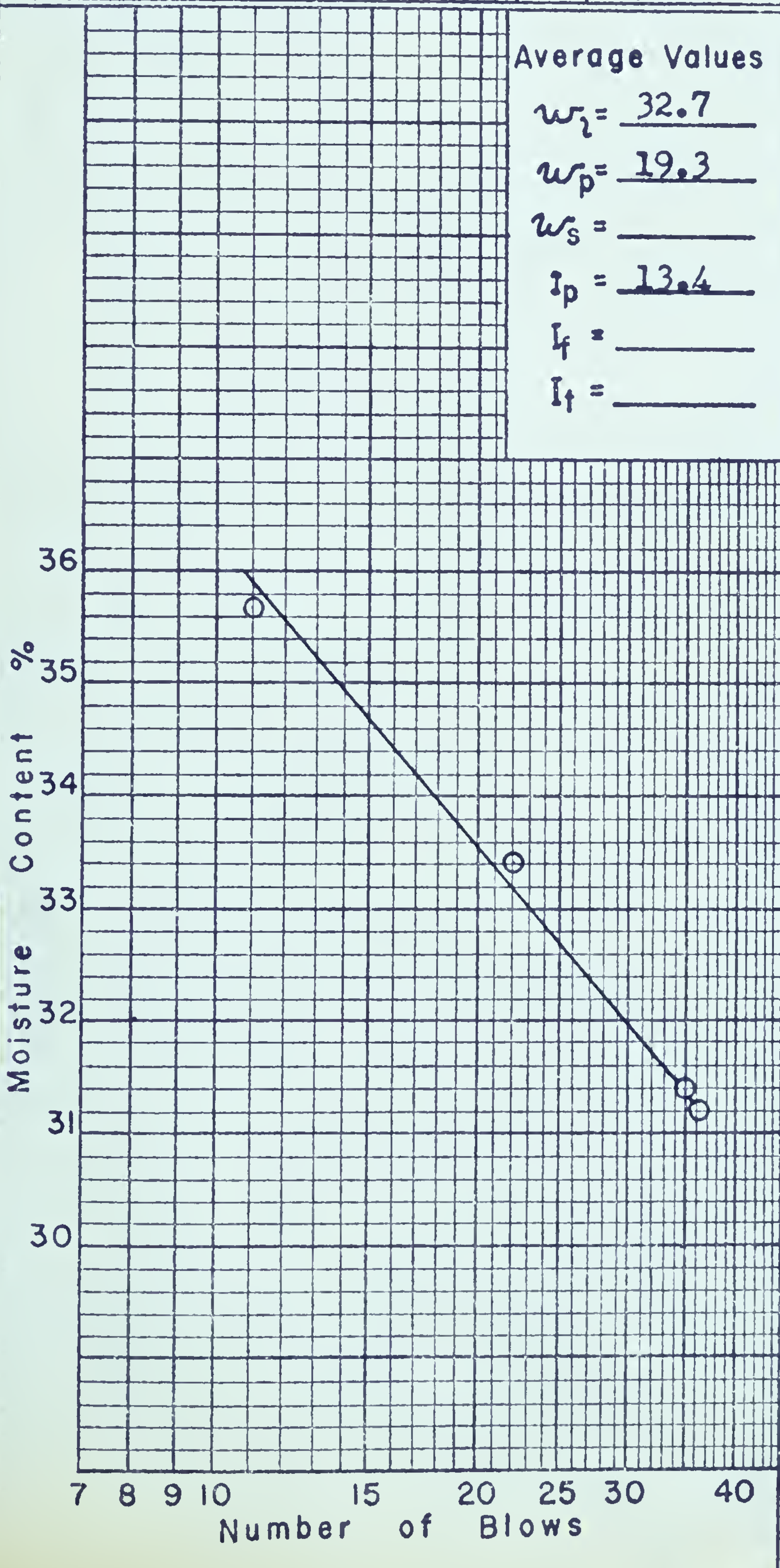
UNIVERSITY of ALBERTA
DEP'T. of CIVIL ENGINEERING
SOIL MECHANICS LABORATORY

ATTERBERG LIMITS

PROJECT	Asphalt Stabilization
SITE	
SAMPLE	Soil 16.C.1
LOCATION	
HOLE	DEPTH
TECHNICIAN DB	DATE July 61

Liquid Limit

Trial No.	1	2	3	4		
No. of Blows	35	36	22	11		
Container No.	V.63	V.65	V.70	V.69		
Wt. Sample Wet + Tare	87.753	90.175	85.434	93.993		
Wt. Sample Dry + Tare	82.760	84.133	79.011	86.353		
Wt. Water	4.993	6.042	6.423	7.639		
Tare Container	66.851	64.785	60.063	64.935		
Wt. of Dry Soil	15.909	19.347	18.948	21.418		
Moisture Content w%	31.4	31.2	33.4	35.7		



Average Values

w_l = 32.7

w_p = 19.3

w_s =

I_p = 13.4

I_f =

I_t =

Plastic Limit

Trial No.	1	2	3
Container No.	B1	B2	B3
Wt. Sample Wet+Tare	44.890	44.762	45.195
Wt. Sample Dry+Tare	43.524	43.400	43.818
Wt. Water	1.366	1.362	1.377
Tare Container	36.395	36.185	36.696
Wt. of Dry Soil	7.129	7.215	7.122
Moisture Content %	19.3	18.9	19.8

Shrinkage Limit

Trial No.			
Container No.			
Wt. Sample Wet + Tare			
Wt. Sample Dry + Tare			
Wt. Water			
Tare Container			
Wt. of Dry Soil W_o			
Moisture Content w%			
Vol. Container V			
Vol. Dry Soil Pat V_o			
Shrinkage Vol. $V-V_o$			
Shrinkage Limit w_s			

$$w_s = w - \left(\frac{V-V_o}{W_o} \times 100\right)$$

Description of Sample:

Remarks:

UNIVERSITY of ALBERTA DEP'T. of CIVIL ENGINEERING SOIL MECHANICS LABORATORY **SPECIFIC GRAVITY**	PROJECT Asphalt Stabilization SITE SAMPLE Soil 16-C-1 LOCATION HOLE DEPTH TECHNICIAN DB DATE June 61

Sample No.			
Flask No.	B1	B 2	B3
Method of Air Removal		Vacuum	
W_{b+w+s}	760.84	755.95	749.97
Temperature T	21.8	21.4	21.4
W_{b+w}	702.08	696.47	691.82
Evaporating Dish No.			
Wt. Sample Dry + Dish	296.72	284.52	285.41
Tare Dish	204.21	198.84	193.59
W_s	92.51	85.68	91.82
G_s	2.74	2.74	2.73

W_{b+w+s} = Weight of flask + water + sample at T°.

W_{b+w} = Weight of flask + water at T° (flask calibration curve).

W_s = Weight of dry soil

G_s = Specific gravity of soil particles $= \dfrac{W_s}{W_s + W_{b+w} - W_{b+w+s}}$

Determination of W_s from wet soil sample:

Sample No.			Sample No.		
Container No.			Container No.		
Wt. Sample Wet + Tare			Wt. Test Sample Wet + Tare		
Wt. Sample Dry + Tare			Tare Container		
Wt. Water			Wt. Test Sample Wet		
Tare Container			W_s		
Wt. of Dry Soil					
Moisture Content w %					

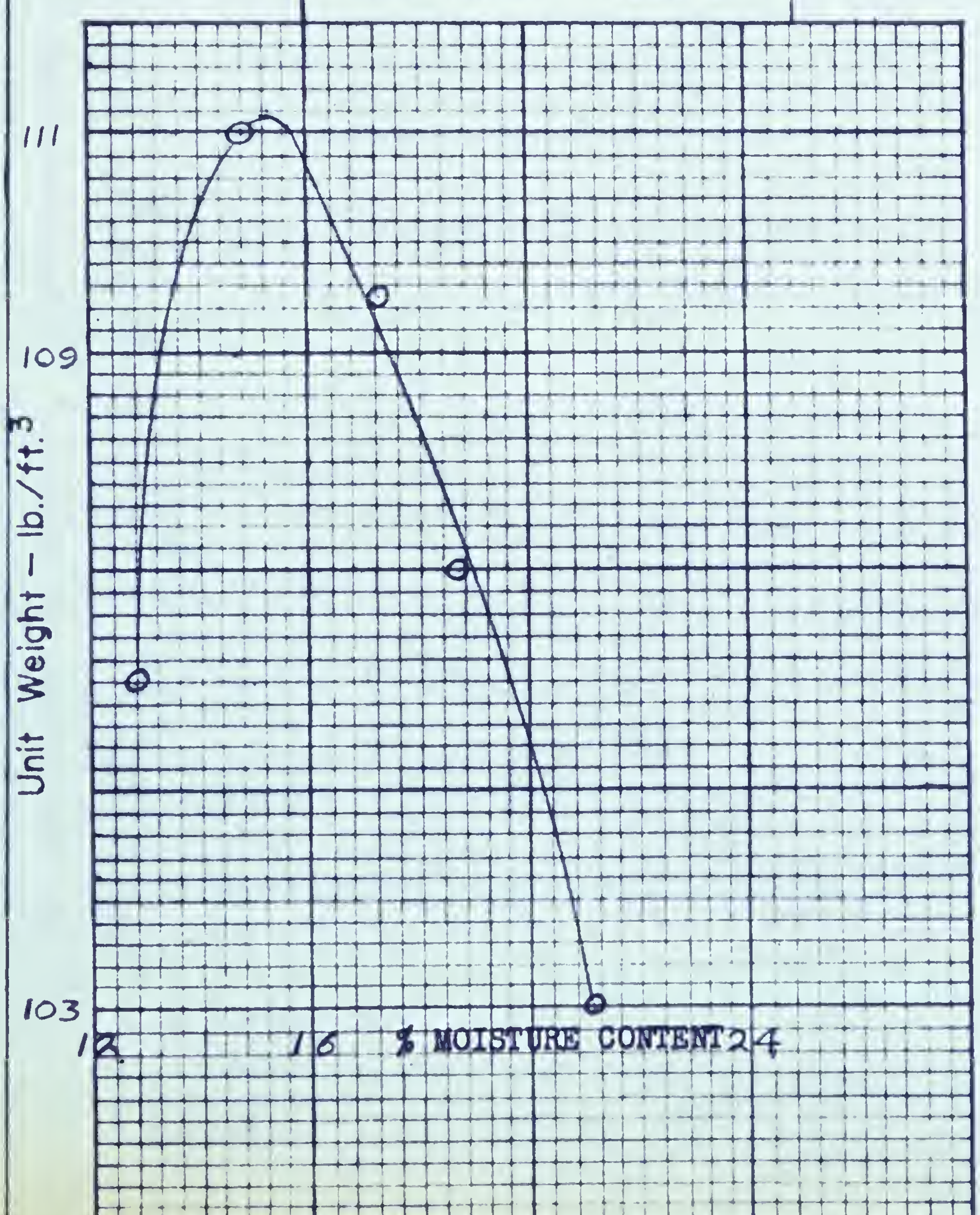
Description of Sample: Light brown colour when in the air dry state.

Remarks:

R.C.A.F. STN. LINCOLN PARK, CALGARY. No. I CONSTRUCTION ENGINEERING UNIT SOIL MECHANICS LABORATORY	PROJECT Asphalt Stabilization SITE SAMPLE Soil 16-C-1 LOCATION
COMPACTION TEST	HOLE DEPTH TECHNICIAN DB DATE June 61

	Trial Number	1	2	3	4	5		
Unit Weight Determination	Mold No.							
	Wt. Sample Wet + Mold	3538	3660	3685	3661	3625		
	Wt. Mold	1738	1738	1738	1738	1738		
	Wt. Sample Wet	1800	1922	1947	1923	1887		
	Volume Mold	0.33	0.33	0.33	0.33	0.33		
	Wet Unit Weight lb./ft.^{3}	119	127	128.5	127	125		
	Dry Unit Weight lb./ft.^{3}	106	111	109.5	107	103		
Moisture Content Determination	Container No.	A27	V63	V59	V51	X1		
	Wt. Sample Wet + Tare	121.371	103.720	111.297	113.664	124.930		
	Wt. Sample Dry + Tare	114.736	98.977	105.134	105.112	115.418		
	Wt. Water	6.635	4.743	6.163	8.552	9.512		
	Tare Container	62.819	66.845	69.497	59.241	70.397		
	Wt. Dry Soil	51.917	32.132	35.637	45.871	45.021		
	Moisture Content	12.8	14.8	17.3	18.7	21.1		

Max. Unit Wt. 111.2 "ft.^{3}
Opt. Moist. = 15.3 %



Method of Compaction Standard Proctor

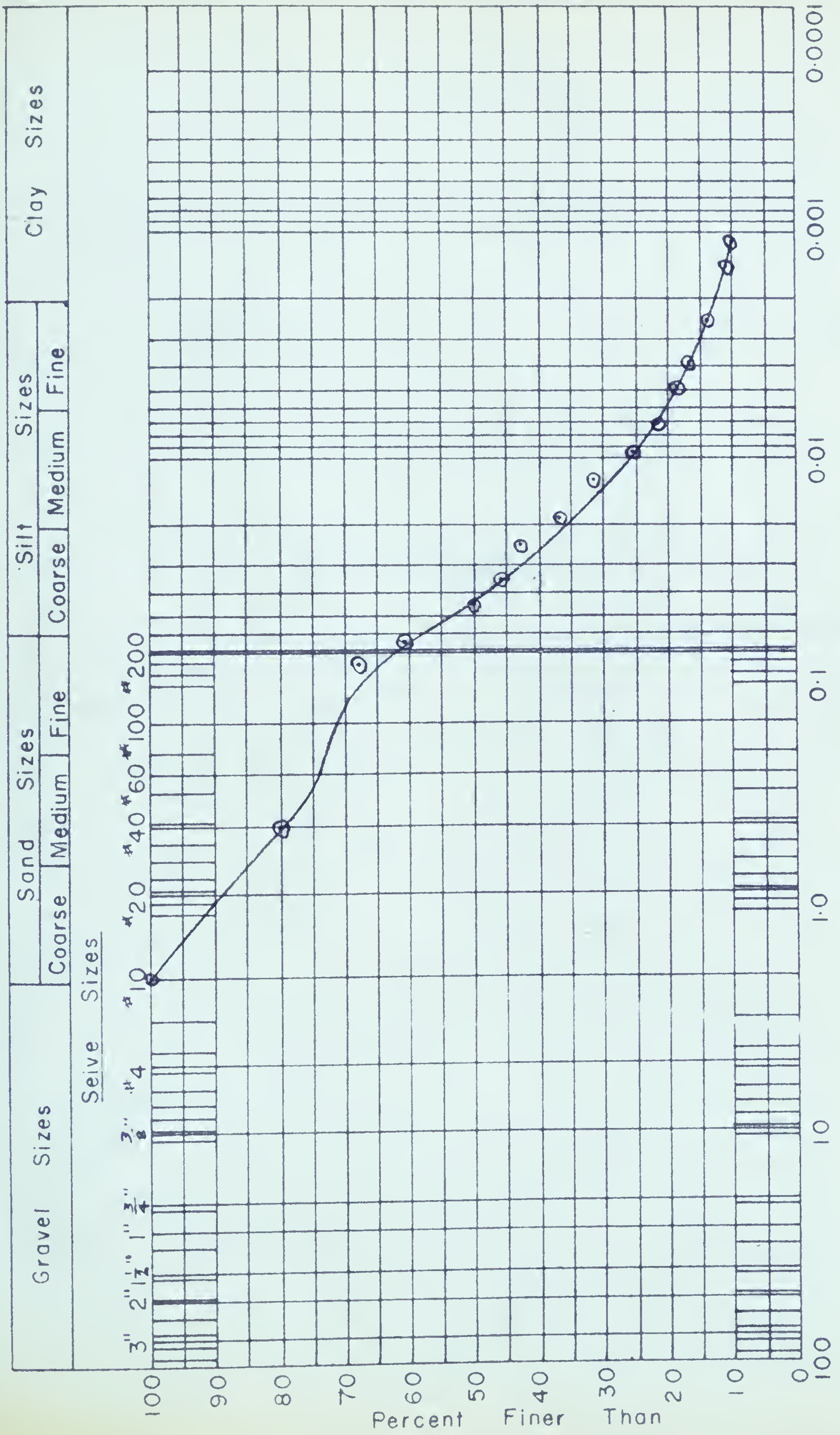
Diam. Mold
Height Mold
Volume Mold
No. of Layers 3
Blows per Layer 25
Ht. of Free Fall 12"
Wt. of Tamper 5.5#
Shape of Tamping Face 0
Description of Sample Silty Clay

Remarks

RCAF STN. CALGARY (Lincoln Park)
Nº 1 Construction Engineering Unit
Soil Mechanics Laboratory.

GRAIN SIZE CURVE

PROJECT ASPHALT STABILIZATION	
SITE	
SAMPLE SOIL 16-C-1	
LOCATION	
HOLE	DEPTH
TECHNICIAN D.B.	DATE JUNE 61



D_{10} = 0.001 mm.
D_{60} = 0.065 mm
C_u 65

Remarks: HYDROMETER ANALYSIS OF MINUS #40 MATERIAL

Note: M.I.T. Grain Size Scale

APPENDIX D

SAMPLE DATA SHEETS

DATA SHEET FOR
SIMULATED STANDARD PROCTOR SPECIMENS

ASPHALT MC-2 ; % ASPHALT 8
METHOD OF TREATMENT 24 hr aeration at 110°F

SPECIMEN PROPERTY	SPECIMEN NUMBER					
	1	2	3	4	5	6
LENGTH (in.)	2.019	2.014	2.021	2.002	1.972	2.056
DIAMETER (in.)	2.00	← MOULD	DIAMETER →			2.00
WEIGHT (gr.)	139.3	137.5	139.5	136.6	134.7	140.3
STRAIN GAUGE						
START	430	445	445	465	500	422
FINISH	490	490	490	500	547	463
STRESS GAUGE DIVISIONS TO FAILURE	8	8	8	9	11	7
FAILURE TOTAL LOAD (lbs)			AVERAGE	40		
STRENGTH (#/in²)			AVERAGE	12.7		

AVERAGE SPECIMEN WEIGHT 138.0 gr

AVERAGE SPECIMEN LENGTH 2.014 in

TOTAL VOLATILES AT COMPACTION 1.3 %

DRY DENSITY 77.5 lb/cu ft

REMARKS:

Dry density of soil plus asphalt residue — 81.8 lb./cu ft. Specimen 7 to 12 inclusive not tabulated as they disintegrated upon soaking.

DATA SHEET FOR SIMULATED MODIFIED PROCTOR SPECIMENS

ASPHALT MC-2 ; % ASPHALT 8

SPECIMEN PROPERTY	SPECIMEN NUMBER					
	SOAKED			AIR CURED		
	1	2		3	4	
COMPACTION						
LENGTH (in)	2.045	2.016		1.990	1.987	
DIAMETER (in)	2.01	2.01		2.01	2.01	
WEIGHT (gr)	211.4	206.6		203.9	204.6	
AIR CURED WEIGHT (gr)	196.5	192.2		189.4	189.9	
SOAKED						
LENGTH (in)	2.043	2.012				
DIAMETER (in)	2.01	2.01				
WEIGHT (gr)	209.7	206.3				
STRESS No. DIVISIONS	316	262		252	254	
FAILURE LOAD (lb)	70.	58		242	243	
STRENGTH (#/in²)				77	77	
AV. STRENGTH	20			77		
AV. LENGTH				1.993		
AV WEIGHT				204.2		
AV. COMPACTION TOTAL VOLATILES	11.9			11.9		
AVERAGE DRY DENSITY	104			104		
PER CENT EXPANSION	5.4					
PER CENT ABSORPTION	7.3					

REMARKS:

Wet compacted specimens

DATA SHEET FOR HUBBARD - FIELD SPECIMENS

ASPHALT MC-0 ; % ASPHALT 8

SPECIMEN PROPERTY	SPECIMEN NUMBER					
	SOAKED			AIR CURED		
	1	2	3	4	5	6
COMPACTION						
LENGTH (in)	1.98	2.02	2.00	2.01	1.99	2.00
DIAMETER (in)	2.00	2.00	2.00	2.00	2.00	2.00
WEIGHT (gr)	217.0	222.0	218.1	219.9	217.9	219.8
AIR CURED						
WEIGHT (gr)				210.5	208.3	210.2
SOAKED						
LENGTH (in)	2.03	2.07	2.06			
DIAMETER (in)	2.06	2.06	2.06			
WEIGHT (gr)	222.8	227.9	224.3			
EXTRUSION (kg)	58.5	54.5	49.5	1380	1225	
AVERAGE EXTRUSION (lb)	118			2930		
AVERAGE EXPANSION (%)	9.5					
AVERAGE ABSORPTION (%)	3.2					
AV. TOTAL VOLATILES AT COMPACTION	10.1			10.1		
% AIR VOIDS AT COMPACTION	3.2			3.2		

SINGLE SPECIMEN 7 DAY AIR CURED q_u 329 #/in²

$\gamma_d = 114$

REMARKS:

Sample #6 was q_u tested

DATA SHEET FOR HUBBARD - FIELD SPECIMENS

ASPHALT 150-200 AC ; % ASPHALT 5

SPECIMEN PROPERTY	SPECIMEN NUMBER					
	SOAKED			AIR CURED		
	1	2	3	4	5	6
COMPACTION						
LENGTH (in)	1.98	2.02	1.986	2.03	2.00	2.00
DIAMETER (in)	2.00	2.00	2.00	2.00	2.00	2.00
WEIGHT (gr)	211.1	215.6	211.7	216.9	214.3	214.8
AIR CURED WEIGHT (gr)				194.3	192.4	193.0
SOAKED						
LENGTH (in)	2.015	2.05	2.02			
DIAMETER (in)	2.06	2.06	2.06			
WEIGHT (gr)	214.1	218.1	214.8			
EXTRUSION (kg)	28	28	26	3320	350	3270
AVERAGE EXTRUSION (lb)	61			7400		
AVERAGE EXPANSION (%)	9.5					
AVERAGE ABSORPTION (%)	1.6					
AV. TOTAL VOLATILES AT COMPACTION	14.5			14.5		
% AIR VOIDS AT COMPACTION	1.9			1.9		

SINGLE SPECIMEN 7 DAY AIR CURED q_u 440 #/in²

$\gamma_d = 108$

REMARKS:

APPENDIX E

SAMPLE CALCULATIONS

For simulated Standard Proctor data sheet of Appendix D:

$$\text{Moulded density} = \frac{(138)\ (1728)}{(454)\ (3.14)\ (2.014)} = 83.0 \text{ lb./cu. ft.}$$

Residual asphalt = (8) (0.73) = 5.84%

Total volatiles at compaction = 1.3%

Total = 7.14%

∴ dry density (assuming the specific gravities of residual asphalt and total volatiles equal 1.00) =

$$\frac{83.0}{107.14} = 77.5 \text{ lb./cu. ft.}$$

For simulated Modified Proctor data sheet of Appendix D:

$$\text{Average compacted weight} = \frac{211.4 + 206.6}{2} = 209 \text{ gr.}$$

Total volatiles = 11.9%

$$\text{Weight of dry specimen} = \frac{209}{1.119} = 187 \text{ gr.}$$

$$\text{Weight after absorption} = \frac{209.7 + 206.3}{2} = 208.0 \text{ gr.}$$

$$\text{Weight before absorption} = \frac{196.5 + 192.2}{2} = 194.4 \text{ gr.}$$

$$\text{Per cent absorption} = \frac{(208.0 - 194.4)\ 100}{187} = 7.3$$

$$\text{Per cent expansion} = \frac{(2.044)^3\ (100)}{(2.01)^3} - 100 = 5.4$$

Air voids calculations for 5% 150 - 200 AC Hubbard-Field data sheet of Appendix D:

Average compacted weight of specimens 1, 2, and 3 - 212.8 gr.

Average volume = $(3.14)(1.993)(2.54)^3 = 102.6$ cc.

Total volatiles at compaction, on a soil plus residual asphalt basis = 14.5%

Weight of soil plus asphalt residue = $\frac{212.8}{114.5} = 186$ gr.

Weight of soil = $\frac{186}{1.05} = 177$ gr. = 95.3% of dry specimen

Specific gravity of soil = 2.74

Weight of asphalt residue = 186 - 177 = 9 gr. = 4.7% of dry specimen

Specific gravity of asphalt = 1.03

Specific gravity of compacted dry mixture = $\frac{186}{102.6} = 1.82$

Theoretical maximum density = $\dfrac{100}{\frac{95.3}{2.74} + \frac{4.7}{1.03}} = \frac{100}{39.4} = 2.54$

Per cent air voids of dry compacted mixture =

$\frac{(2.54 - 1.82)(100)}{2.54} = \frac{72}{2.54} = 28.3$

Volatiles at compaction = 212.8 - 186 = 26.8 gr.

Percentage volume of specimen = $\frac{26.8 (100)}{102.6} = 26.4$

$\therefore$ per cent voids at wet compaction = 28.3 - 26.4 = 1.9%